POWER SYSTEM PROTECTION & CONTROL

STAGE 3B-PSP105

TEXTBOOK/WORKBOOK

POWER SYSTEM PROTECTION & CONTROL

STAGE 3B-PSP105

TEXTBOOK/WORKBOOK

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POWER SYSTEM PROTECTION & CONTROL

STAGE 3B-PSP105

COURSE OVERVIEW

OVERVIEW

After completion of this course, the trainee will have the necessary knowledge and skills to identify the different types of power transducers and its applications in power energy meters. The course also scopes out the communication systems as high-speed protection tools.

Digital relays are also included in this course, starting with the relay hardware, software, and the digital relay applications provided with practical tasks for different types of digital relays.

OBJECTIVES

Upon completion of this course, the trainees will be able to:

- List the different types and their ideas of power transducers.
- Explain the importance of power energy meters in the power networks.
- Classify the high-speed protection tools as communication systems.
- Explain the theory and operation of fiber optics applications.
- Explain the digital relay structure as hardware and software.
- Identify the applications of numerical relays.

CONTENTS

The contents of the (3B) course material are divided into three (3) units of instructions with eleven (11) lessons.

Also, different types of digital relays should be performed to installation and test as a part of its applications for the relay technician duties.

Text and workshop material

Unit 1	Power Instruments
Unit 2	High Speed Protection
Unit 3	Numerical Relays

DURATION

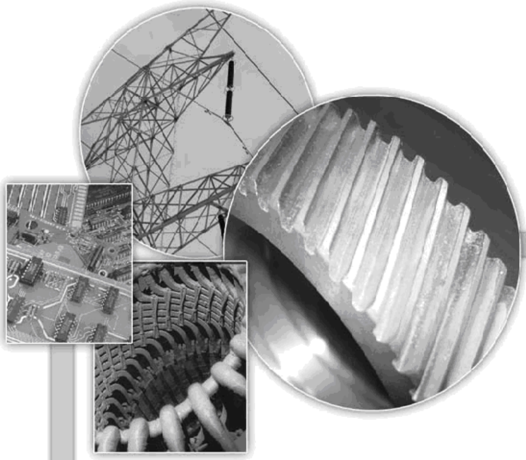
This course is for duration of nine (9) weeks to cover theoretical part, practical tasks, and field visits.

POWER SYSTEM PROTECTION & CONTROL
STAGE 3B-PSP105

PACING SCHEDULE

TEXTBOOK/WORKBOOK

Unit	Description	Duration (Hours)
1	Power Instruments	25
2	High Speed Protection	50
3	Numerical Relays	125
	TOTAL	**200**



UNIT 1

POWER INSTRUMENTS

UNIT-1
POWER INSTRUMENTS

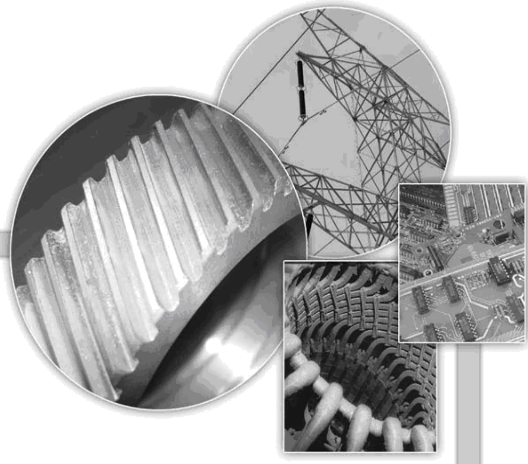
OVERVIEW

This unit discusses the electrical power measurements including the necessary transducers and the power energy meters. The unit browses the types of power transducers and the purpose of using energy meters in transmission and substations.

OBJECTIVES

Upon completion of this unit, the trainee will be able to:

- Classify the types of power transducers.
- Explain the purpose of using the energy meters.
- Demonstrate the installation and calibration for the energy meters.



LESSON 1.1

POWER TRANSDUCERS

LESSON 1.1
POWER TRANSDUCERS

OVERVIEW

This lesson discusses the types of transducers that involves with the relay technician works especially in the metering of electrical power quantities. The lesson scopes out ideas of different types of transducers.
Involves

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Classify the transducers.
- Identify thermal transducer and its applications.
- Identify Hall transducer and its applications.
- Identify Rogowski transducer and its applications.
- Demonstrate power transducer and perform check.

INTRODUCTION

Transducer is defined as a device that receives one or more types of physical quantities to produce one type of another quantity. Common transducers sense and transmit information for a wide range of different energy forms such as current, voltage, pressure, temperature, movement, magnetic energy etc. A microphone, for example, converts sound waves that strike its diaphragm into an analogous electrical signal that can be transmitted over wires. A pressure sensor turns the physical force being exerted on the sensing apparatus into an analog reading that can be easily represented. Transducer serves the technician of power system protection in the following applications:

- Temperature.	- Pressure.
- Current.	- Voltage.
- Active power (Watt).	- Reactive power (Var).
- Energy (kWh).	- Frequency.
- Phase angle.	- DC current.

For example, Watt-transducer receives current and voltage from instrument transformers, then produces milli ampere or milli volt signal that proportional to the input signals. Other devices receive these micro signals to apply some processes to compute, store, or indicate the measuring values.

There are many different types of both analogue and digital input and output devices available to choose from them. The type of input or output transducer being used, really depends upon the type of signal or process being "Sensed" or "Controlled"

SENSOR

Sensor is a device that performs an input function, because it senses a physical change in some characteristic that changes in response to some excitation, for example temperature or speed and converts that into proportional electrical signals. Generally, all types of sensors can be classed as two types, **passive** and **active**.

ACTIVE SENSORS

Active sensors normally require external power to operate, called an excitation signal, which is used by the sensor to produce the output signal. Active sensors are self-generating devices because their own properties change in response to an external effect and produce an output voltage, for example, (1 – 10V) DC or an output current such as 4 to 20mA DC. For example, a strain gauge is a pressure-sensitive resistor. It does not generate any electrical signal, but by passing a current through it (excitation signal), its resistance can be measured by detecting variations in the current and/or voltage across it relating these changes to the amount of strain or force.

PASSIVE SENSORS

Unlike the active sensor, a passive sensor does not need any additional energy source and directly generates an electric signal in response to an external stimulus. For example, a thermocouple or photodiode. Passive sensors are direct sensors, which change their physical properties, such as resistance, capacitance, or inductance etc.

EFFICIENCY

As in all energy conversions, some energy is lost when transducers operate. The efficiency of a transducer is found by comparing the total energy put into it to the total energy coming out of the system. Some transducers are very efficient, and others are inefficient.

Electrical energy is one example of an efficient transducer. It depends on the quality and characteristics of internal components and transformer core material inside the transducer if any.

ANALOGUE SENSOR

Analogue Sensor produces a continuous output signal or voltage, which is generally proportional to the quantity being measured. Physical quantities such as Temperature,

Speed, Pressure, Displacement, Strain etc are all analogue quantities, as they tend to be continuous in nature. For example, the secondary current of a CT can be measured using current transducer as shown in Fig. 1.1-1. The transducer responds to current changes as the primary current increases or decreases, and produces output signal.

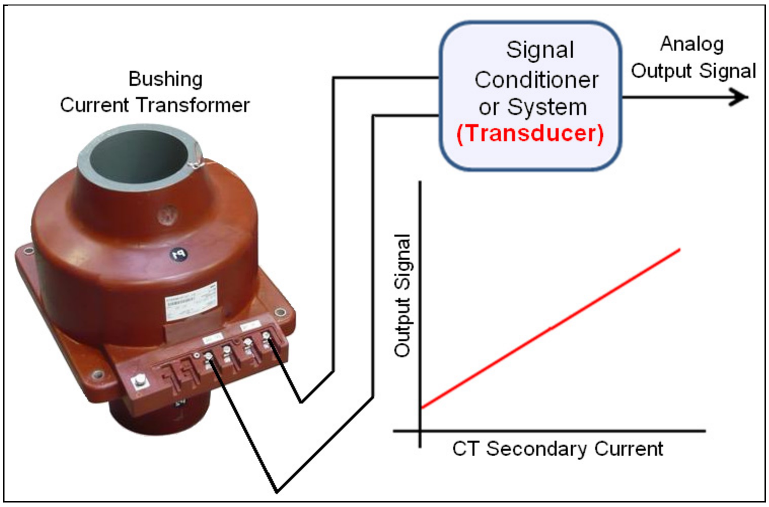


Fig. 1.1-1 Using Current Transformer to Produce Analogue Signal

Analogue sensor tends to produce output signal that is changing linearly and continuously, which is very small in value so some form of amplification is required. The circuits that used to measure analogue signals usually have a slow response and/or low accuracy.

DIGITAL SENSORS

Digital Sensors produce a discrete output voltage signal that is a digital representation of the quantity being measured. Digital sensors produce a Binary output signal in the form of logic "1" or logic "0", ("ON" or "OFF"). This means then that a digital signal only produces discrete (non-continuous) values, which may be outputted as a single "bit", (serial transmission) or by combining the bits to produce a single "byte" output (parallel transmission).

In fact, some types of digital sensors are an analogue sensors provided with analogue to digital converter (A/D). It facilitates operating with microprocessor systems or wide lanes to transmit information remotely.

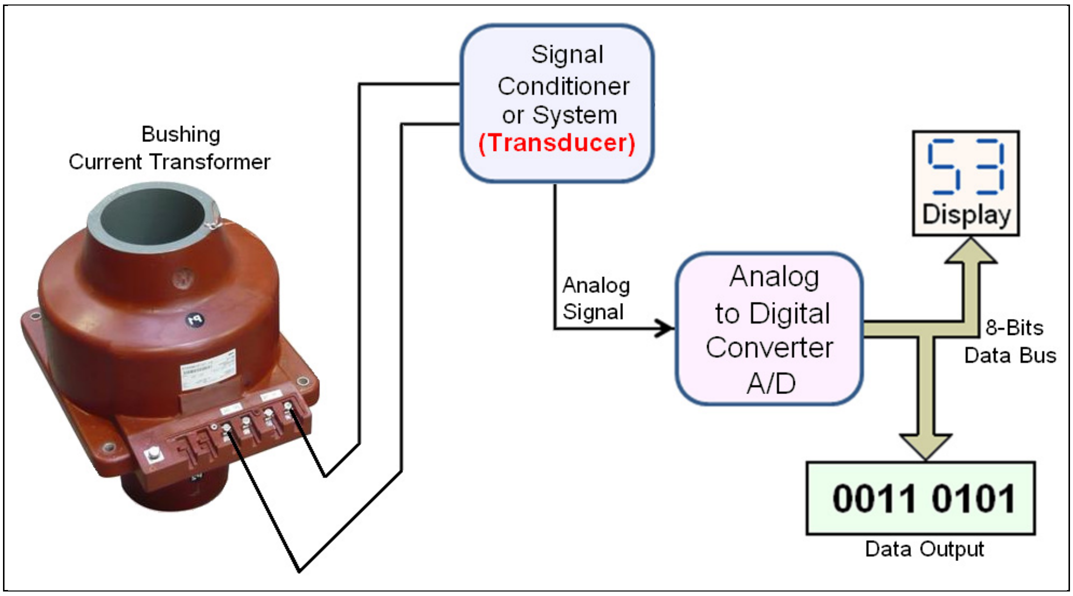


Fig. 1.1-2 Using Current Transformer to Produce a Digital Signal

In Fig. 1.1-2, an A/D converter unit is added to the current transducer sensor to perform digital output signal. As the primary current changes, the data output is vary linearly and the display value is accordingly.

Compared to analogue sensors, digital sensors have high accuracies and can be both measured and "sampled" at few microseconds. The accuracy of the digital sensor is proportional to the number of bits used to represent the measured quantity. For example, using a processor of 8-bits will produce an accuracy of 0.195% (1 part in 512). While using a processor of 16-bits gives an accuracy of 0.0015%, (1 part in 65,536) or 130 times more accurate. This accuracy is recommended as digital quantities are manipulated for millions of times faster than analogue signals.

In most cases, sensors and more specifically analogue or digital sensors generally require an external power supply and some forms of additional amplification and filtering of the signal in order to produce an acceptable electrical signal, which is capable of being measured or used. One very good way of achieving both amplification and filtering within a single circuit is to use operational amplifier as in the following example.

CURRENT TRANSDUCER

Current-to-Voltage Transducer produces a 0-5 VDC or 0-10 VDC output signal that is directly proportional to the input AC current. The output signal is average sensing for RMS. Current transducer is used with process control and industrial instrumentation equipment. The DC output signal can be connected directly to a high impedance analog input of a microcontroller system or PLC with additional signal conditioning.
Accuracy of current transducer depends on the range and load resistance. An external current transformer may be used with the transducer by routing the secondary leads through the window opening, Fig. 1.1-3.

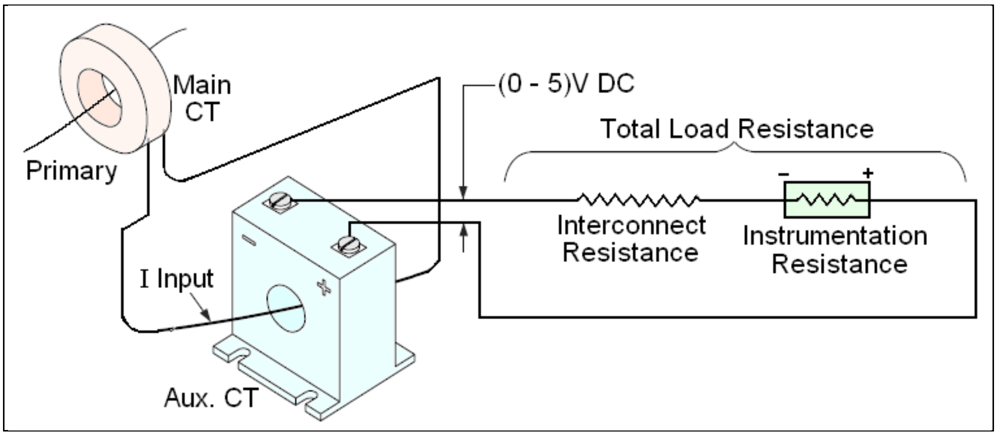


Fig. 1.1-3 Current to Voltage Transducer

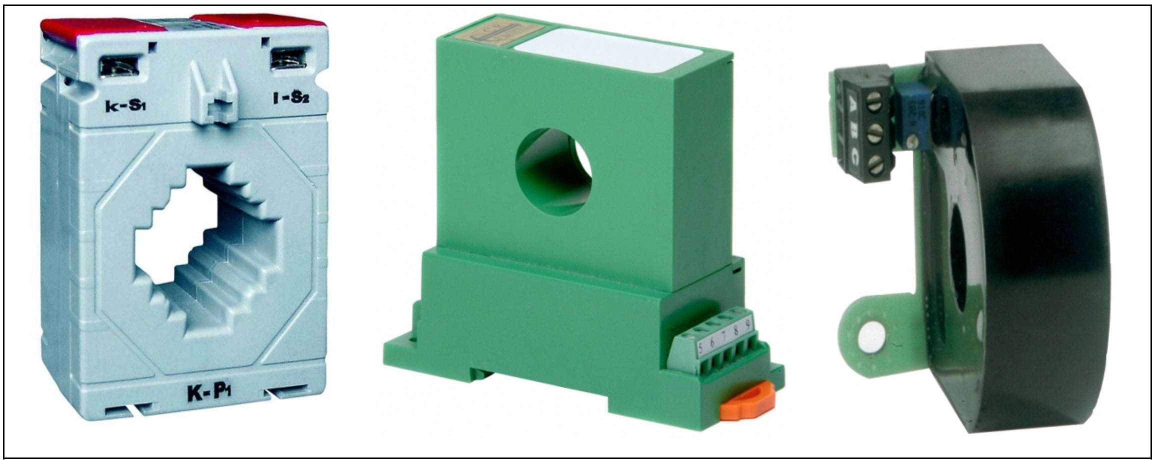


Fig. 1.1-4 Different Types of Current Transducers

VOLTAGE TRANSDUCER

AC voltage transducers measure AC voltage either directly or through a voltage transformer. The transducer converts the AC voltage signal to either a DC mA or DC voltage output, which is directly proportional to the input signal value. Voltage transducer is average sensing rms calibrated. Voltage transducer is used for a permanent monitoring of a single-phase voltage and frequency values. It may operate with PLC, SCADA system, and communication networks.
A simple construction for the voltage transducer is as shown in Fig. 1.1-5.

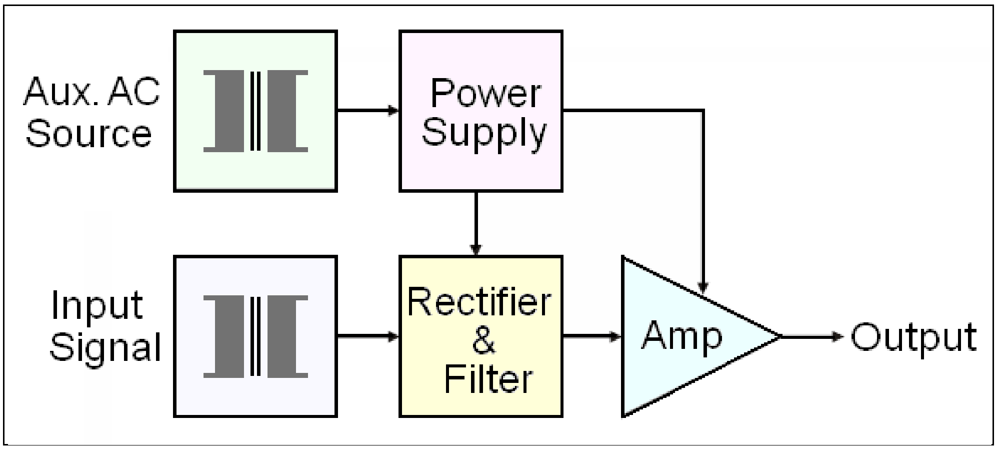


Fig. 1.1-5 Construction of Voltage Transducers

Fig. 1.1-6 Different Types of Voltage Transducers

HALL-EFFECT TRANSDUCER

Hall voltage is generated when an external current passes through a hall plate and a magnetic field is exist perpendicular to the plate surface as shown in Fig. 1.1-7.

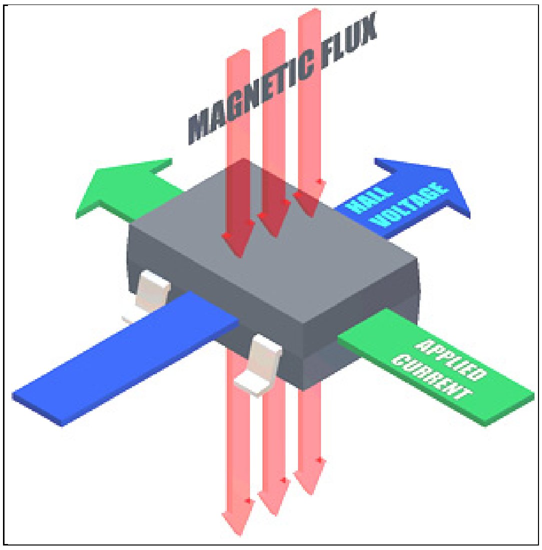


Fig. 1.1-7 Generating Hall Voltage from Hall Element

Hall element can be used to detect double input quantities, such as active power and reactive power. The output voltage (E_H) is proportional to the product of an electric current and magnetic field input. Fig. 1.1-8 shows the basic schematic of Hall Effect power transducer.

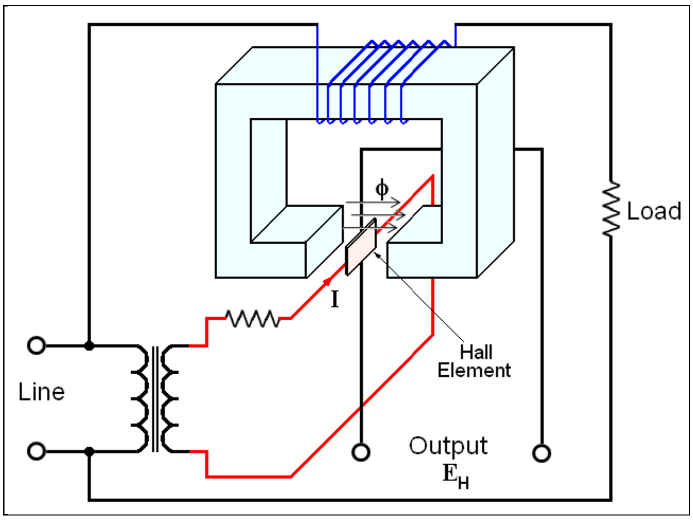


Fig. 1.1-8 Basic Schematic of Hall Effect Power Transducer

The line current $I_L = [I\cos\omega t + \varphi\ ]$ flows through a coil on the magnetic circuit setting up a magnetic field in the air gap which is proportional to current. A potential transformer supplies a control current to the Hall element, which is proportional to the line voltage. Since the output of the Hall device is a product function, the ideal output voltage of Hall device is:

$$E_H = KE\cos\omega t\, I\ \cos(\omega t + \ \varphi)$$

Or
$$E_H = KEI\cos\varphi + KEI\cos(2\omega t + \ \varphi)$$

The first term of the above equation is a D.C. component and proportional to the true power. The second term is double frequency A.C. component, which is proportional to volt-amperes.

When using single-phase output to drive a meter or recorder, the A.C. can generally be ignored. If the output is being fed into an amplifier, it may be desirable to filter out the A.C. component.

In three-phase watt transducer, when operating on a balance system it has no A.C. component because of self-canceling. Fig. 1.1-9 shows examples of power transducers.

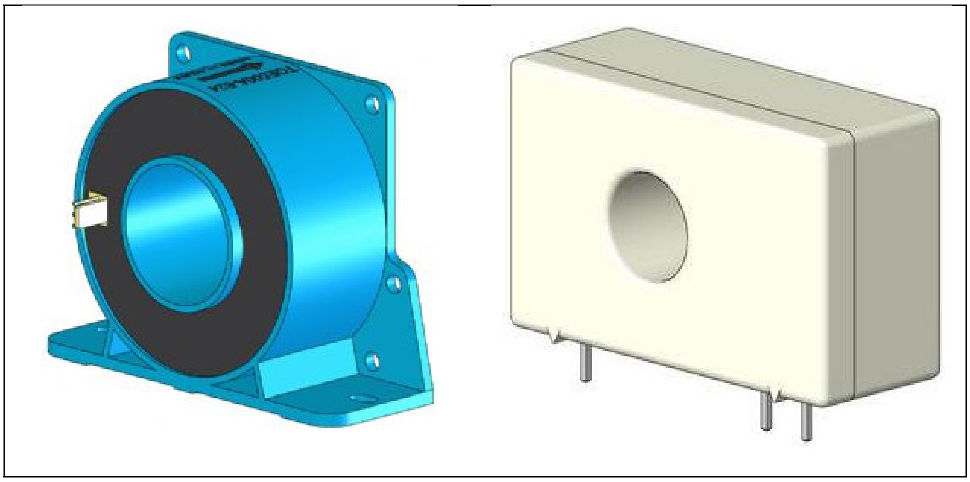


Fig. 1.1-9 Different Types of Hall Transducers

The produced hall voltage is proportional to the amount of passing current while the magnetic field is fixed. This type of transducer is used in AC & DC current transducers because of its sensitivity, linearity, and fast response.

VAR TRANSDUCER

A var transducer is used to measure reactive power EI $\sin\varphi$. These measurements can be made by a well-known technique that is the use of watt transducer and a phase shifting potential transformer. In this method, the input potential is shifted 90° before being fed to a watt transducer. In three-phase application, the phase shift transformer usually consists of a pair of tapped autotransformers (with voltage balanced).
Another method is the use of cross-connected watt transducer connected in the system such that the potential input from one phase and the current input from another phase are used. The connections are chosen so that in a balanced system the voltage and current are in quadratic zone.

Fig. 1.1-10 shows single-phase Var transducer module.

Fig. 1.1-10 Var Transducer

CAPACITIVE TRANSDUCER

This type of transducers is used to convert linear or rotational movement to capacitance value. Measuring the change in capacitance through a change in distance between two opposite plates, or measuring capacitance change through a change in overlapping area as shown in Fig. 1.1-11.

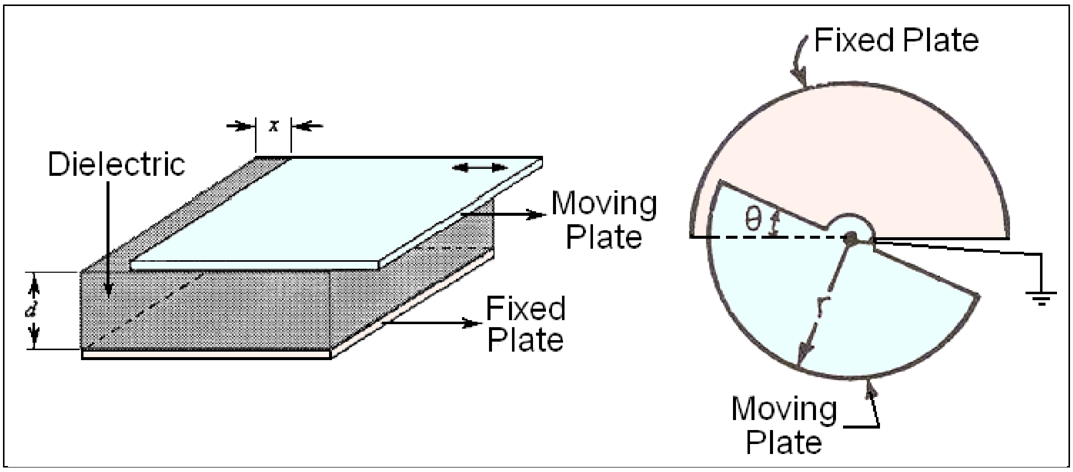


Fig. 1.1-11 Simple Capacitive Displacement Transducer

Capacitive sensors can directly sense a variety of things. Such as motion, chemical composition, electric field and, indirectly, sense many other variables which can be converted into motion or dielectric constant, such as pressure, acceleration, fluid level, and fluid composition.

They are built with conductive sensing electrodes in a dielectric, with excitation voltages on the order of five volts and detection circuits, which turn a capacitance variation into DC voltage (0 - 5V), or DC current (0 – 20mA)

Capacitive sensors have a wide variety of uses, some of them serve PSP applications such as liquid level detector, which senses the liquid level in a reservoir by measuring changes in capacitance between conducting plates which are immersed in the liquid, or applied to the outside of a non-conducting tank.

ROGOWSKI TRANSDUCERS

A Rogowski transducer usually comprises a thin, flexible, clip-around coil attached by a cable to an integrator as shown in Fig. 1.1-12. The coil-induced voltage is proportional to the rate of change of current enclosed by the loop. The integrator voltage is therefore proportional to the instantaneous current.

Fig. 1.1-12 Rogowski Current Transducer and its Enclosing Semiconductor Package

Rogowski current transducers are an excellent tool for measuring long range of current in the power system. Rogowski current transducers are often used to measure fast switching rapid current transients in the power system networks.

Fig. 1.1-13 Typical Rogowski Current Transducer

ROGOWSKI TRANSDUCER APPLICATIONS

- Measuring devices, lab instrumentation
- Power monitoring & control systems
- DC ripple measurement
- Harmonics and transients monitoring

USING TRANSDUCERS

Transducers are utilized to measure the various electricity parameters. These transducers include types to measure watts, vars, volts, amperes, frequency, and phase-angle. Power system operation, load control, and dispatching require the telemetering of many quantities from substations, generating stations, and tie points to central control rooms. Some of the quantities to be telemetered are watts, vars, current, voltage, phase angle, frequency, and temperature.

All of these quantities, and others, may be easily telemetered after first being converted to a proportional DC current by an appropriate solid-state transducer. Transducers are now an important part of measurement and control for efficient use of plant and equipment; measurements must be made quickly and accurately, then fed to an indicating instrument, or passed for further processing to equipment such as SCADA, data processors, or computers. In general, terms a transducer maybe regarded as a conventional measuring instrument connected in the normal way to the main transformers.

Instead of the movement of a pointer, the transducer output is a DC analogue current signal, which is proportional to that function of the input requiring measurement, as shown in Fig. 1.1-14.

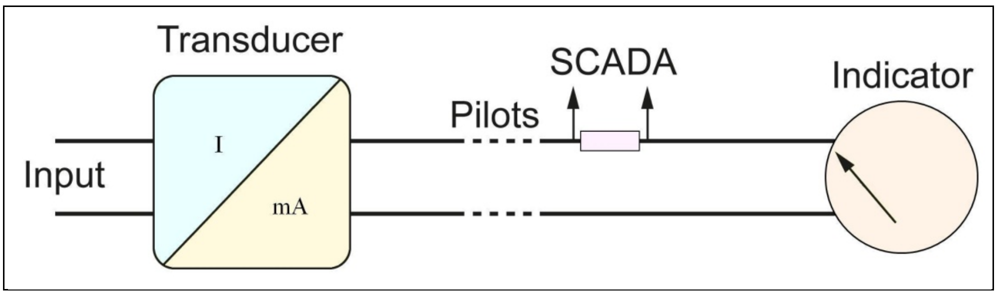


Fig.1.1-14 Using Current Transducer

The transducer has multifunction including electric parameters acquisition, detecting switching value and control. It can measure almost all parameters of 3-phase 4-wire circuit including voltage, current, frequency, active power, reactive power, power factor, accumulated energy consumption, and switching value.

POWER TRANSDUCER APPLICATIONS

Fig. 1.1-15 shows some types of power transducers.

Fig.1.1-15 Some Types of Power Transducers

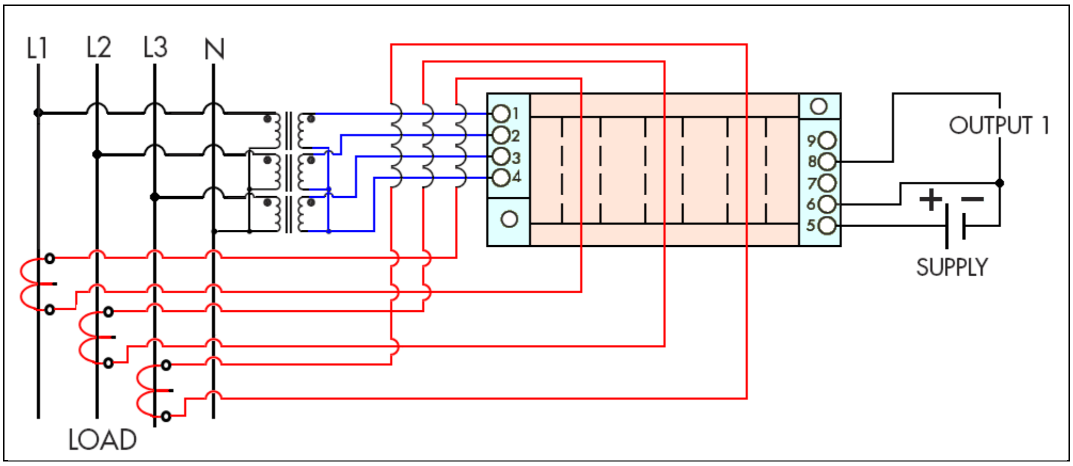


Fig. 1.1-16 Three-Phase Active Power Transducer Connection

TYPICAL SPECIFICATIONS

Input Current: 1A & 5A (from CT)

Input Voltage: 100V, 110V & 120V (from VT)

Output Current: 4 – 20mA DC

Output Voltage: 0 – 5V DC

DC Supply Voltage: 12V – 24V DC

SUMMARY

- Transducer is a device that detects and converts physical quantity to electrical signal (current or voltage signal).
- Sensor is an input device that detects physical quantity depending on its sensitivity.
- Transducer efficiency actually depends on the quality of internal components.
- Analogue sensors tend to produce output signals that are changing smoothly and continuously.
- Digital sensors produce a Binary output signal in the form of "1" or "0".
- Capacitive transducer is used to convert linear or rotational movement to capacitance.
- Hall transducer produces a voltage that proportional to the amount of passing current through the Hall element at the presence of perpendicular magnetic field.
- Voltage transducer normally consists of input transformer, rectifier, filter, and precision amplifier.
- Rogowski transducer is a thin, flexible, clip-around coil attached by a cable to an integrator.
- Rogowski transducer is the best choice to detect harmonics, transient, and DC ripples.
- Most transducers are used to provide information about dynamic physical quantities to indicators, SCADA systems, automation, recorders, database systems, and most digital systems.

GLOSSARY

Transducer:	Device that converts input physical quantity into output electric signal.
Sensor:	Device that detect physical quantity depending on its sensitivity.
Stimulus:	Incentive that affects the controlled variable in a control system.
Serial transmission:	Passing data bit by bit.
Parallel transmission:	Passing data 8 bits at the same time.
Register:	Location to record temporary information.
Telemeter:	Measuring data by remote system.
Data acquisition:	Getting hold of information.
Automation:	Using technology to ease the control process.
Dynamic quantity:	Variable parameters.
Physical:	Substantial, materiality.

REVIEW EXERCISE

Match between sentences of the opposite columns, by filling the following table:

1. Transducer:	A. Tend to produce output signals that are changing smoothly and continuously.
2. Digital sensors:	B. It is used to convert linear or rotational movement to capacitance.
3. Sensor:	C. Produces a voltage that proportional to the amount of passing current through an element at the presence of perpendicular magnetic field.
4. Capacitance transducer:	D. Actually depends on the quality of internal components.
5. Analogue sensors:	E. It is used to detect harmonics, transient, and DC ripples.
6. Transducer efficiency:	F. Produces a Binary output signal in the form of "1" or "0".
7. Rogowski transducer:	G. A device converts physical quantity to electrical signal.
8. Hall transducer:	H. Used as input device that detects physical quantity depending on its sensitivity.

1	2	3	4	5	6	7	8

TASK 1.1-1
CHECKING TRANSDUCER

OBJECTIVE

Upon completion of this task, the trainee will be able to check power transducer.

TOOLS, MATERIALS & REQUIREMENTS

- Power transducer (3-phase, 4-wires).
- Milli-ammeter.
- Secondary injection test set (AC current & AC voltage).
- DC power supply (0 – 24VDC).
- AC Voltmeter.
- AC Ammeter.

SAFETY PRECAUTIONS

The participants must wear safety clothes and follow all safety instructions as recommended in the relay workshop.

PROCEDURE

1. Receive the power transducer from your instructor.
2. Apply visual inspection test to check its inputs and outputs.
3. Check the transducer data on the nameplate.
4. Construct the active power transducer pinout diagram as shown in Fig. 1-1.
5. Identify the power supply terminals and apply the required DC voltage to its terminals.
6. Connect milli-ammeter at the mA output terminals.
7. Connect the transducer input voltage terminals (V_R) and Neutral (N) to the secondary injection tester and adjust it at 100V with angle zero.

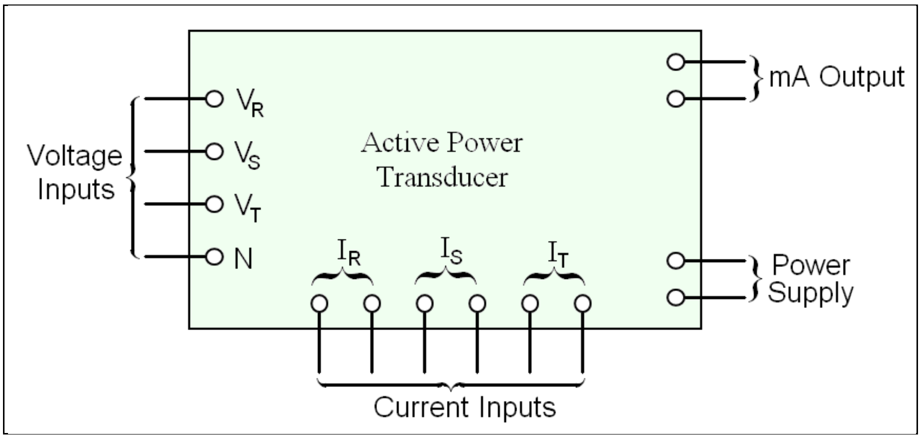


Fig. 1-1 Pin-out Diagram of Active Power Transducer

8. Connect the transducer input current terminals (I_R) to the secondary injection test set and adjust its current at 1A with angle zero.
9. The equivalent output current is obtained from the equation:

$$P = V_R \, I_R \, \cos\theta$$

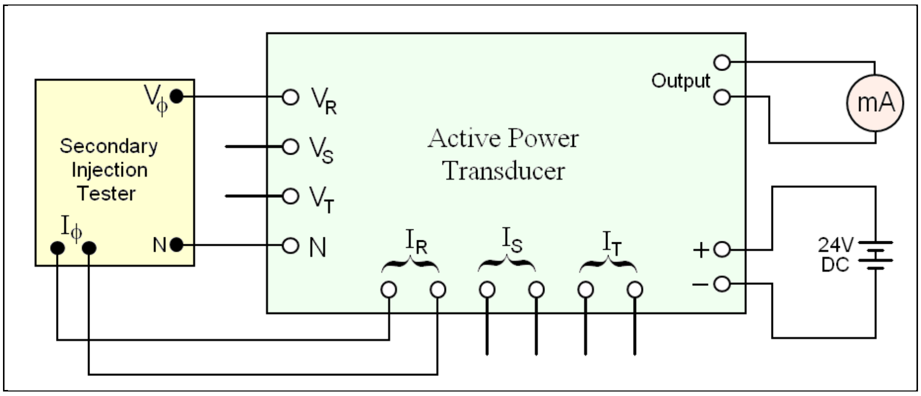
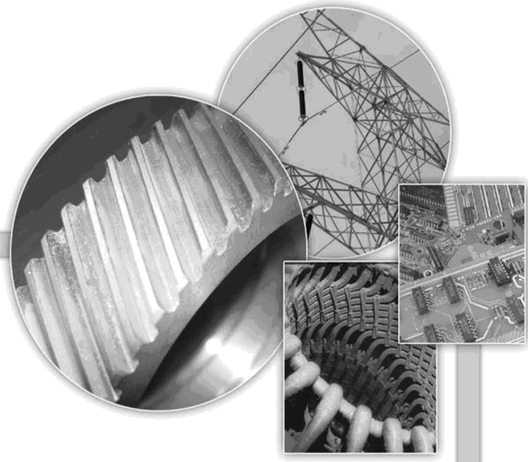


Fig. 1-2 Connection Diagram for Checking Active Power Transducer

10. The amount of output milli-ampere is proportional to the active power.
11. Monitor and record the output current on the milli-ammeter.
12. Increase the input current to 2A, and monitor the output current.
13. The expected current output should be doubled.
14. Change the input current angle of (I_R) to 60^o.
15. The expected current output should be decreased to the half.
16. Repeat steps (7 - 15) for phases (S) & (T).
17. Switch off all sources and make housekeeping.



LESSON 1.2

POWER & ENERGY METERS

LESSON 1.2
POWER & ENERGY METERS

OVERVIEW

This lesson discusses the power energy meters that used in transmission and substations to measure active power, Vars, import and export power, and the max. demands of the cumulative values of the record quantities. The lesson scopes out the installations and the energy meter calibration.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Identify the energy meters.
- Illustrate the impotance of energy meter in power stations.
- Verify the installation of energy meter.
- Identify the requirements for meter installation.
- Demonstrate the energy meter calibration.

INTRODUCTION

Electrical energy meter (kWh or MWh meter) is an instrument that measures the amount of electrical energy supplied to a residential or commercial building. There are many types of energy meters, electromechanical, electronic (static), and digital (programmable) types. The domestic communities types are not a part of the power system protection technican jobs. The propsal types are used to measure large amount of power especially in the industrial plants, commercial bulding, transmission and distribution power plants.

These type of meters can record energy usage at different times of day and even different forms of power (i.e., real versus reactive) to enable multi-rate billing (multi tariff). They provide improved measurement accuracy and significant lower power consumption than mechanical meters. Now a days, most the electronic energy meters are programmable, allowing a basic hardware design to be easily reconfigured by software for different applications. A major benefit is the provision of automatic meter reading, the ability to collect data via networked communication by a method of remote data transmission.

Electrical energy meters are used in substations to measure how much power is delivered according to entering certain amount of fuel, how much power is lost, the import and export energy especially for the commercial power plants, which purchase electricity to/from the electrical utility.

Electrical energy meters can record the events of interrupts, maximum demand, shutdown, and faults. Most electronic energy meters can be joined with local or wide area networks (LANs & WANs) to be easily communicated and controlled remotely.

Smart electric meters are fundamental to the successful operation of smart grid technology, as they improve grid reliability and user consumption control and reduce electricity theft. The variety of consumers emerging needs requires a much wider offering of energy metering systems-on-chip. Energy meter-specific analog front-end devices, which combine high performance with cost reduction. Today's energy metering standards demand higher accuracy and lower power consumption, which in turn, challenges system designers to deliver more competitive smart ICs. Digital

energy meter depends on high-performance analog-to-digital converter (ADC) with a programmable gain amplifier. A microcontroller is used to organize all operations inside the meter.

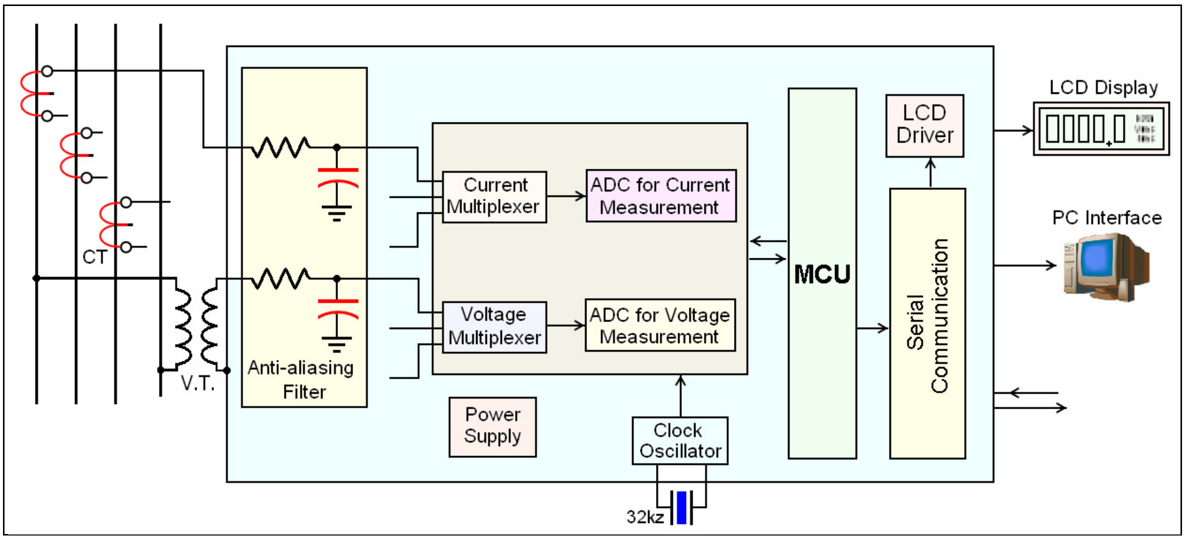


Fig. 1.2-1 System Block Diagram for three phase Energy Meter

Fig. 1.2-1 shows a system block diagram for a three-phase energy meter. As shown the energy meter hardware includes a power supply, an analog to digital converter, a microcontroller section, real-time clock, liquid crystal display (LCD), communication ports/modules, and anti-aliasing filter.

The analog front end is the part that interfaces to the high voltage lines. It converts high voltages and high currents to voltages sufficiently small to be measured directly by the ADC (Analog/Digital Converter) of the microcontroller. Digital signal processing is used to compute the different energy metrics, such as instantaneous, active, and reactive power; voltage/current value; and power factor. A micro controller unit (MCU) manages all the energy meter operations.

The energy meter inputs can be entered either directly from instrument transformers through analog to digital converter unit (ADC) or transducers, as the hardware construction of the meter manufactureres. A certain program is stored on a microcontroller unit to organize all the meter performed functions.

FEATURES OF ENERGY METER

1. The meter should be switched to operate for many accuracy classes applications
2. The meter can detect emported and exported energy.
3. The meter should be programmed to day time metering
4. The meter can be joined with optical communication port.
5. The meter can be programmed to record the cumulative consumption of kWh every certain period of time (monthly as an example).
6. The meters shall have facilities to display the kWh consumption and the Maximum Demand, and display other necessary data when required.
7. The meters shall be programmed via a hand held programming unit or function keys with facilities for down loading of readings to a data logger/PC (IBM Compatible).
8. The meters shall display the stored cumulative consumption of kWh, maximum demand and the maximum demand reset count when required ;
9. The meters shall preferably record accurately irrespective of the phase sequence of supply.
10. The meter shall operate normally, even in the absence of neutral & when any two voltage leads are connected.
11. The following information should be fed to the meter program before operation:
    - Station information
    - Operational voltage
    - Voltage transformer ratio
    - Secondary current
    - Current transformer ratio
    - Frequency
    - Tariff identification

12. The meter operator should follow the following:
    - Personal safety against electric shock.
    - Personal safety against effects of excessive temperature;

- Safety against spread of fire
- Protection against penetration of solid objects, dust, and water.

Voltage interruptions shall not produce a change in the readings as it is stipulated.

POWER CALCULATIONS

The energy meter should perform the following calculations:

- Power grid frequency
- RMS voltage of each phase
- RMS current of each phase
- RMS neutral current
- Active power of each phase
- Reactive power of each phase
- Apparent power of each phase
- Power factor of each phase
- Fundamental active power of each phase
- Fundamental reactive power of each phase
- Harmonic active power of each phase
- Harmonic reactive power of each phase
- Total active power:
  - The algebraic sum of active power of three phases
- Total reactive power:
  - The algebraic sum of reactive power of three phases
- Total apparent power:
  - The algebraic sum of apparent power of three phases
- Total power factor
- Phase missing / line voltage sag detection and alarm
- Total active energy:

- The algebraic sum of positive/negative active energy

- Positive/negative active energy
- Positive/negative reactive energy
- Four-quadrant reactive energy
- Voltage/current harmonic content of each phase

ENERGY METER INSTALLATION

All connections for energy meter are dependent on the choice of current sensing element and a secondary external transformer may be required in higher current meter designs.

STEP 1:
CONNECT THE ENERGY METER TO THE LINE VOLTAGE AND LOAD

The diagram below shows where the voltage and current connections should be made. It is not required to connect all 3 phases for the meter to be operational. AC line voltage should be placed between either VA, VB, VC or neutral. The AC load for a given phase should then be connected to the I_{IN} and I_{OUT} of a given phase.

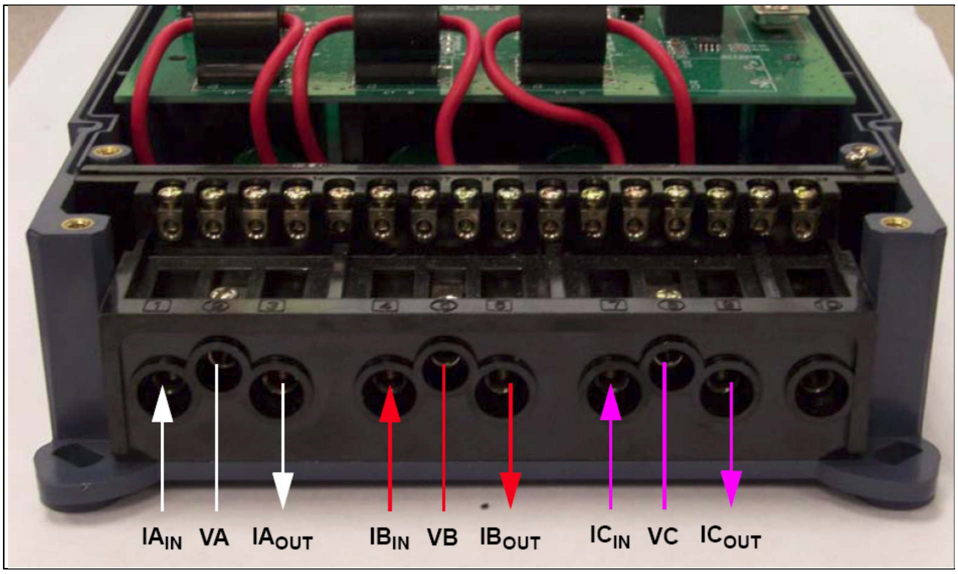


Fig. 1.2-2 Connection of Energy Meter Terminals

STEP 2:

TURN ON LINE/LOAD POWER TO THE METER

Turn on the power to the energy meter. The meter should be light showing the meter has power. At this point, if a load is connected and the meter is measuring power, the power LED of the energy meter should be blinking.

STEP 3:

CONNECT THE DATA CABLE RS-232 OR ANY SUITABLE CONNECTION

1. Connect the RS-232 cable from the energy meter to a Personal Computer (PC), using the suitable communication port (COM1, COM2, ….).

STEP 4:

RUN THE PC CALIBRATION SOFTWARE

After checking the system required and be sure it agrees with the used PC, install and run the PC energy meter software on a PC running a Windows Operating System, and selecting the proper communication port for RS-232 cable, the following screen should show real-time meter results.

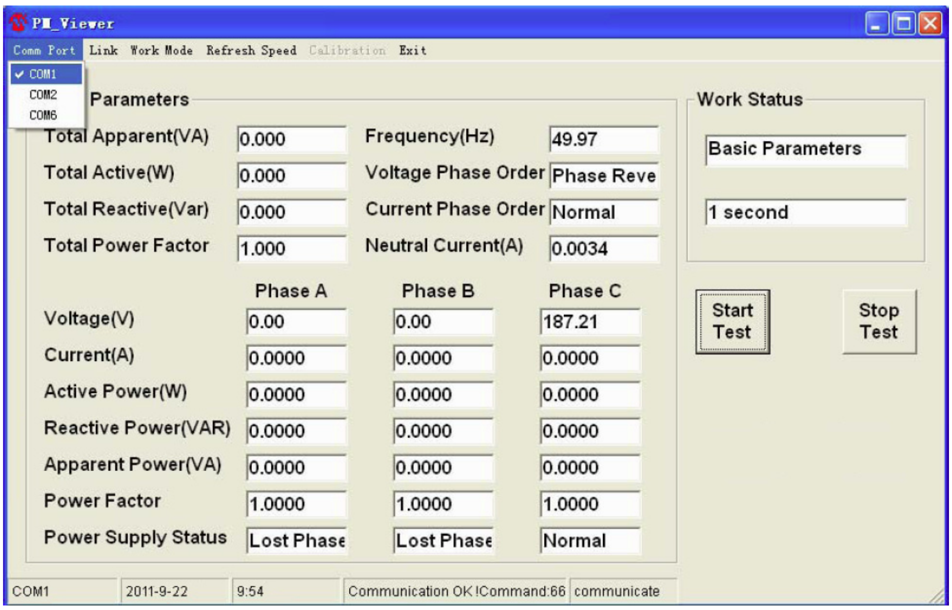


Fig. 1.2-3 Power Meter Viewer PC Software

STEP 5:

Adjust date/ time of the energy meter either from the meter software or manually on the meter buttons

STEP 6:

Inter the meter name, the station name and the bus number, which required to connect.

STEP 7:

Set the auxillary transformer turns ratio, the maximum demand, the events to be recorded, the double tariff deuration time the inturrupt cases which required to register. Set also the polling time to fetch the information to the meter.

STEP 8:

The comulative record can be get back either directly on the meter, or by connecting the PC on line with the meter, by connecting handheld to the meter to fetch their information then downloading the handheld contents on the PC.

Some energy meter provided with an optical port to get the meter information optically by using optical fiber cable

METER CALIBRATION

Meter calibration consists of using standard electrical power equipment that supplies the power to the meter and calculates the error and correction factor at each calibration point. This equipment must be accurate in order to calibrate the energy meter. The supplied PC software is then used to send calibration commands and correction factors down to the meter processor, completing meter calibration.

An energy meter usually has errors due to instrument transformers, reference voltage tolerance, analog to digital converter (ADC) gain errors, and other passive component errors. Energy meters are factory calibrated before shipping to eliminate the impact from such elements and reduce the error. The non-linearity and inconsistency of signals in the path of sampling circuit and A/D conversion circuit cannot be ignored in

high-accuracy measurement. The impact needs to be corrected to improve measurement accuracy. The calibration can be done by the help of the PC software. The idea is to tune some factors to correct the input values this calibration is done automatically when compared with another accurate meter.

APPARENT POWER CALIBRATION

Apparent Power calibration function is implemented using the computer by sending the commands and perform the following processes:

1. Determine the phase to be calibrated according to the parameters received.
2. Calculate new power calibration coefficient according to the error value received and the measured value, together with the original power calibration coefficient.
3. Store the coefficient after correction into the meter memory.

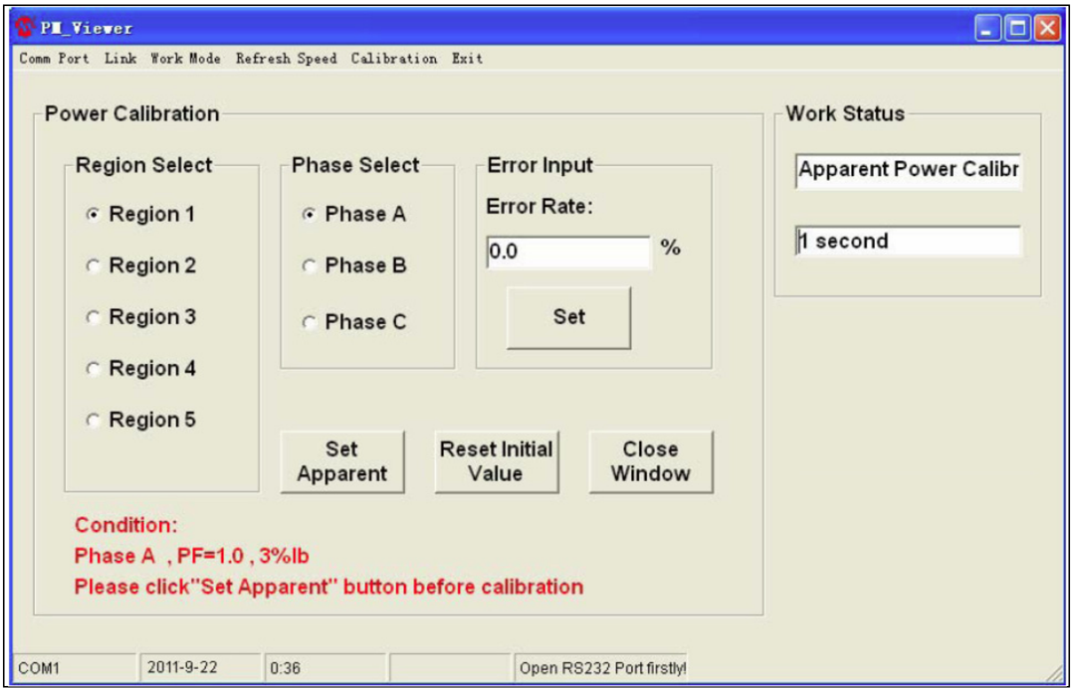


Fig. 1.2-4 Apparent Power Calibration

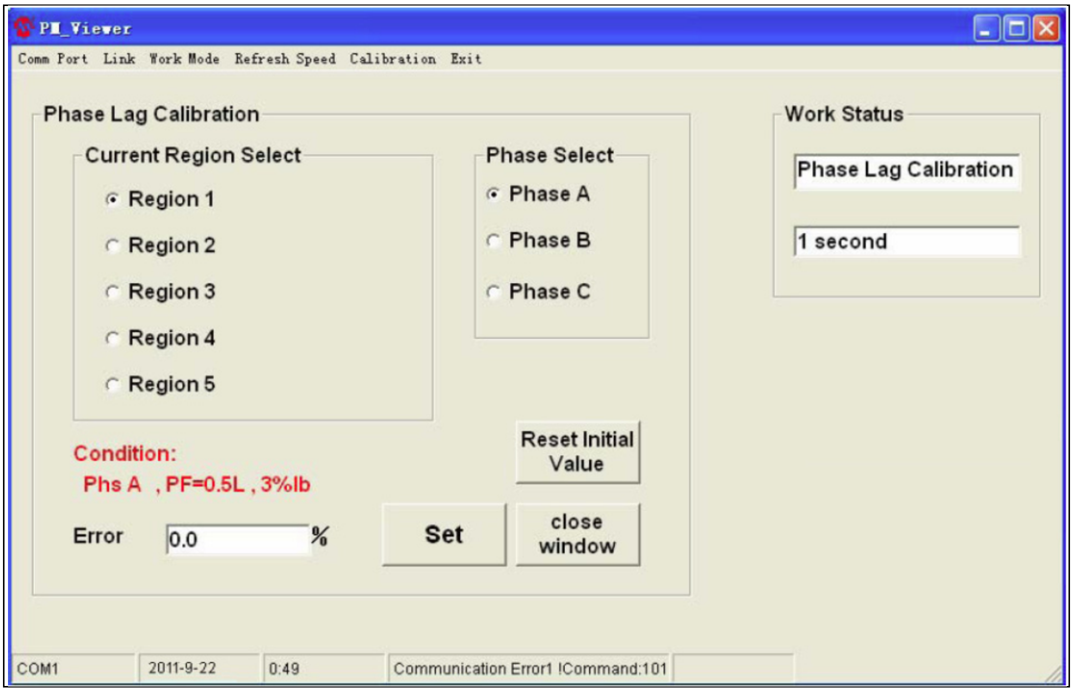


Fig. 1.2-5 Phase Lag Calibration

The calbration can be made to the following items:

- Current and voltages.
- Apparent power.
- Phase lage.
- Reference meter voltage.

ACTIVE AND REACTIVE ENERGY

Active energy is defined as the integral of active power over time, which is:

$$W = \int_0^T P(t)dt = \sum_{k=0}^{N} u(k).i(k).\Delta t$$

In the energy meter, active energy is obtained from multiplying the voltage by the current sampled each time. The phase angle difference is compensated after each power measurement is completed.

For reactive power, the cumulative reactive energy over a time period can be calculated by measuring the average power and calculating the time interval between two measurements.

POSITIVE/NEGATIVE ACTIVE ENERGY, POSITIVE/NEGATIVE REACTIVE ENERGY AND FOUR-QUADRANT REACTIVE ENERGY

In the energy meter, the horizontal axis denotes voltage vector U (fixed on the horizontal axis). The instantaneous current vector is used to represent the power transfer, and has a phase angle φ against vector U. φ is positive in counter-clockwise direction. Power exchange can be defined in four quadrants:

- Q_1 ($P>0$, $Q>0$): active and reactive energy are sent out at the same time;
- Q_2 ($P<0$, $Q>0$): active energy is sent in while reactive energy is sent out;
- Q_3 ($P<0$, $Q<0$): active energy is sent in while reactive energy is absorbed;
- Q_4 ($P>0$, $Q<0$): active energy is sent out while the reactive energy is absorbed.

1. POSITIVE AND NEGATIVE ACTIVE ENERGY

Accumulated active energy can be defined as positive and negative depending on the direction of active current. When the direction of active current is positive (from power grid to loads), active energy is positive (where active power $P>0$, corresponding to quadrants I and IV, which means that loads are drawing energy from grid). When current moves from loads to power grid, it is defined as negative active energy (where active power $P < 0$, corresponding to quadrants II and III, which means energy is provided to grid). Usually only positive active energy is taken into account, but in practice negative active energy may be taken into account as well, if happened.

2. POSITIVE AND NEGATIVE REACTIVE ENERGY

If reactive power $Q > 0$ (corresponding to quadrants I and II), it means power grid is providing reactive energy to loads, so the energy is defined as positive reactive energy. When reactive power $Q < 0$ (corresponding to quadrants III and IV), it means that loads are providing reactive energy to power grid, so the energy is defined as negative reactive energy.

3. **FOUR-QUADRANT REACTIVE ENERGY**

Metering reactive energy in positive/negative reactive energy cannot truly reflect the status of reactive energy, whereas 4-quandrant reactive energy measuring gives a true picture of energy exchange. Reactive energy in four quadrants represents four different reactive energy (see Fig. 1.2-6). The reactive energy is accumulated depending on which quadrant it is located.

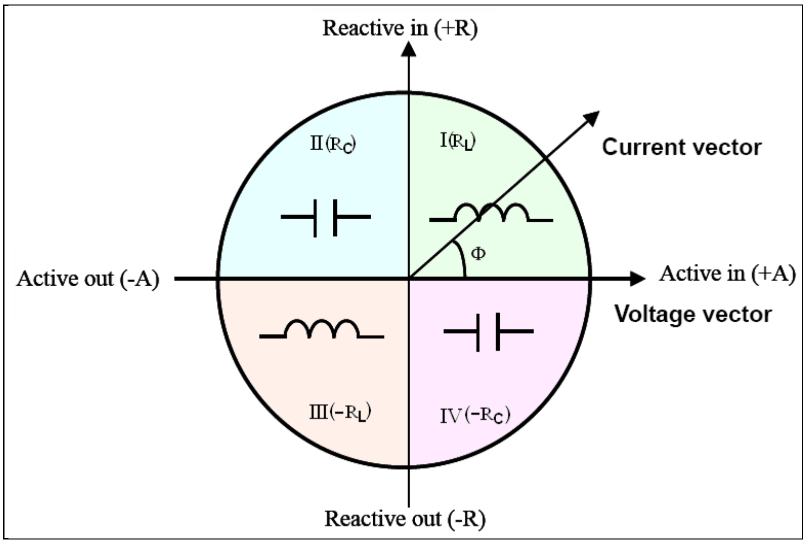


Fig. 1.2-6 Definition of 4 Quadrants to Measure Electrical Energy

Where:

A = is active energy,

R = is reactive energy

R_L = is inductive reactive energy

R_C = is capacitive reactive energy

Fig. 1.2-7 Different Types of Energy Meters

SUMMARY

- Energy meters are used to record three-phase active power, reactive power, import and export power, max. demand, double tariff, and many other electrical quantities.
- The meter is programmed to set at certain auxiliary transformer turns ratio.
- The meter is also adjusted to record certain events and interrupts.
- The energy meter can differentiate between positive and negative active and reactive power flow.
- The meter can be automatically calibrated for current and voltage, apparent power and phase lag calibration.
- The meter can store a lot of information for long time, until fetching it by handheld, computer connection or by optical port.

GLOSSARY

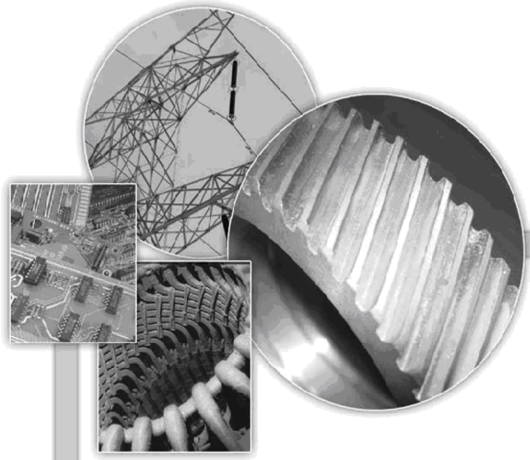
Blink:	Flash
Consistency:	Confusion
Max. demand	Max. instantantanous reading
Double tariff:	Two different power cost in different date

REVIEW EXERCISE

Match between the two colomns, then fill the following table:

1. Optical port:	A. the direction of active current is from grid to load.
2. Max. demand:	B. The reactive energy is accumulated depending on which quadrant it is located.
3. RS232 cable:	C. Is used to fetch data optically.
4. Negative active & reactive energy:	D. It means reactive power is provided from load to graid.
5. Positive active energy:	E. Is used to fetch data at the absence of PC.
6. Four quadrant reactive energy:	F. Is connected between PC and meter.
7. Handheld:	G. It is the max. reading value.
8. Negative reactive energy:	H. the direction of active current is from load to grid.

1	2	3	4	5	6	7	8



UNIT 2

HIGH SPEED PROTECTION

UNIT-2
HIGH SPEED PROTECTION

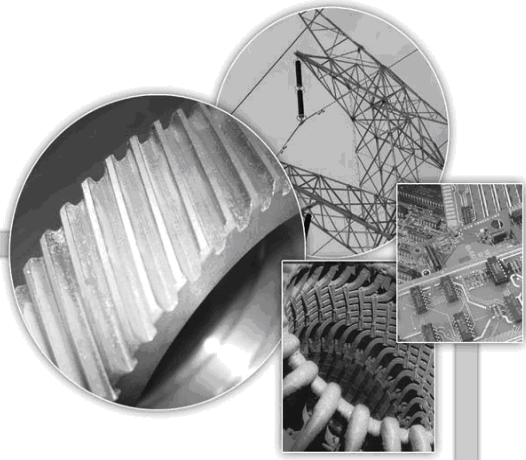
OVERVIEW

This unit discusses the high-speed protection equipment

OBJECTIVES

Upon completion of this unit, the trainee will be able to:

- List the different types of electrical diagrams.
- State the functional tests of the protective relays.
- Explain primary and secondary injection tests for protective relays.
- Define the energization and in-service tests of protective relays.



LESSON 2.1

COMMUNICATION CONCEPTS

LESSON 2.1

COMMUNICATION CONCEPTS

OVERVIEW

This lesson reviews the fundamental concepts of Analog Communications with the universal frequency band allocation chart; the lesson explains the principles of Amplitude and Frequency modulation giving applications of Frequency Shift Keying in a Modem and TCF-10 Transmitter for protective relaying. Finally, the lesson concludes with the introduction to Fiber Optic Communications.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Define communication, information, carrier, modulator, unmodulated carrier, modulated carrier, demodulator, modulation, demodulation, modulating signal, transmission medium, channel, and noise.
- Define different frequency bands in frequency spectrum chart.
- Describe the three characteristics of a sine wave for three types of modulation.
- Explain AM modulation process to generate Modulation Envelope.
- Define Percent AM Modulation and explain how to calculate it.
- Illustrate Under modulation and over modulation with diagrams.
- Explain AM sidebands and bandwidth of an AM system.
- Explain Frequency Domain Analysis.
- Define Amplitude Modulation.
- Explain frequency modulation, frequency deviation, modulation index, FM sidebands, and bandwidth.
- Explain the frequency spectrum of an FSK Modem and TCF-10 Transmitter.
- Explain the principle of Fiber Optic Communication.

INTRODUCTION

Analog Communication is a data transmitting technique in a format that utilizes continuous signals to transmit data including voice, image, video, information etc. An analog signal is a variable signal continuous in both time and amplitude, which is generally carried by use of modulation.

Data is represented by physical quantities that are added or removed to alter data. Analog transmission is inexpensive and enables information to be transmitted from point-to-point or from one point to many. Once the data has arrived at the receiving end, it is converted back into digital form so that, it can be processed by the receiving computer.

COMMUNICATION

Communication is defined as the process of transferring information in terms of voice or data from one point to another.

INFORMATION

Information is defined as the knowledge or intelligence contained in voice or data.

CARRIER

Carrier frequency is a standard fixed or variable high frequency sine wave on which an analog or digital information is superimposed to be transmitted to a distant location. The carrier is generated by a free-running high frequency oscillator circuit.

MODULATOR

Modulator is an electronic circuit that mixes the carrier with the analog or digital information signal to be transmitted. Modulator is also called the Transmitter.

UNMODULATED CARRIER

Unmodulated Carrier is the high frequency carrier, as pure sine wave with no modulating signal.

MODULATED CARRIER

Modulated Carrier is the transmitted high frequency sine wave, carrying the analog or digital information that can be resumed by the receiver.

DEMODULATOR

Demodulator is an electronic circuit that separates the analog or digital information signal from the carrier frequency.

DEVIATION

A shift in carrier frequency above and below its center value depending on the amplitude of the modulating signal in frequency modulation (FM).

TRANSMISSION MEDIUM

A Transmission Medium is the mode or means of transferring information.

The three mediums available for transmission of information are:

- Wire/Cable/Power Line Carrier
- Free Space (RF)
- Fiber Optic

Table 2.1-1 shows different frequency bands allocated to different systems recognized internationally.

DESCRIPTION	SYMBOL	FREQ. RANGE	REMARKS
Very Low Frequency Band	VLF	3kHz - 30kHz	
Low Frequency Band	LF	30kHz - 300kHz	Power Line Carrier
Medium Frequency Band	MF	300kHz - 3MHz	
High Frequency Band	HF	3MHz - 30MHz	SW Band
Very High Frequency Band	VHF	30MHz - 300MHz	Total range of VHF
Very High Frequency Band	VHF	54MHz - 88MHz	TV CH2 - CH6
Very High Frequency Band	VHF	88MHz - 108MHz	FM Broadcast Band
Very High Frequency Band	VHF	174MHz - 216MHz	TV CH7 - CH13
Ultra High Frequency Band	UHF	470MHz - 890MHz	TV CH14 - CH83
Super High Freq. Band	SHF	3GHz - 30GHz	
Extremely High Freq. Band	EHF	30GHz - 300GHz	

Table 2.1-1 Frequency Spectrum

TYPES OF MODULATION

The three basic types of modulation are:

- Amplitude Modulation (AM).
- Frequency Modulation (FM).
- Phase Modulation.

For the study of AM and FM modulation, both the Time and Frequency Domain analysis of the complex waves are important.

TIME DOMAIN ANALYSIS

In Time Domain, the voltage or current amplitude of the waveform varies with time. The understanding of complex waves in time domain is necessary for the study of modulation of the sine wave in frequency domain. Any complex waveform is composed of many sine waves.

A square wave is composed of a fundamental sine wave and an infinite number of odd harmonics. A saw-tooth wave is composed of a fundamental sine wave and an infinite number of odd and even harmonics.

FREQUENCY DOMAIN ANALYSIS

Frequency domain is defined as a logical display orientation of RF (radio frequency) amplitude versus frequency. Frequency Spectrum Analyzer is required to analyze Modulation of RF wave in Frequency domain by displaying the Frequency Spectrum of a modulated or an unmodulated carrier wave. In Frequency Domain, the voltage or current amplitude of the wave varies with frequency, as in time domain the amplitude varies with time.

HARMONICS

Harmonic is another frequency component of a fundamental complex wave and acts an integral multiple of the fundamental wave. Harmonic is expressed as a periodic function, derived from the sum sine and cosine functions by Fourier series in advanced mathematics. The first harmonic as fundamental wave generates the maximum amplitude marker, which generate their own markers at the respective multiple frequencies. Fig. 2.1-1 shows the amplitude versus frequency graph of a fundamental 1 kHz sine wave, as displayed on a Spectrum Analyzer.

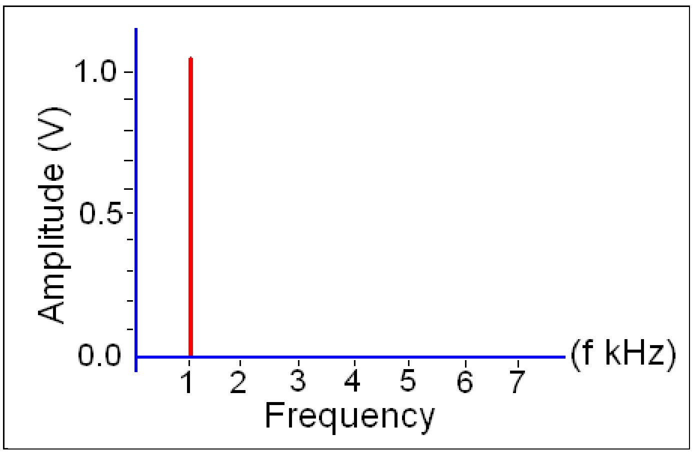


Fig. 2.1-1 Frequency Spectrum for 1 kHz Sine wave

Fig. 2.1-2 shows the frequency spectrum of 1 kHz square wave. A square wave is composed of a fundamental sine wave and an infinite number of odd harmonics. The odd harmonics of the square wave with exponentially decreasing amplitude are indicated at 1 kHz, 3 kHz, 5 kHz, and 7 kHz along the horizontal axis.

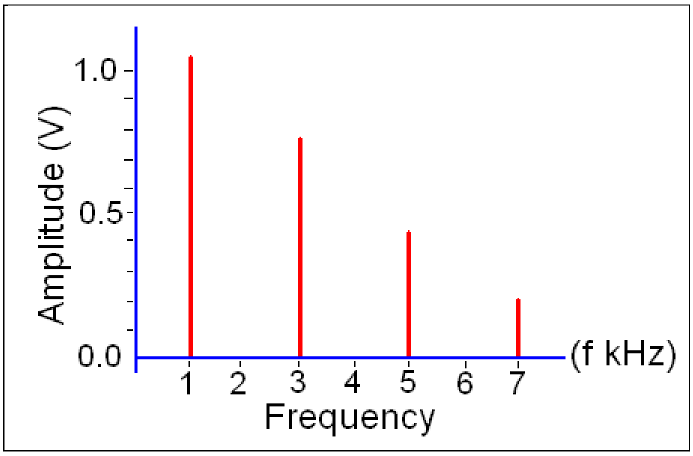


Fig. 2.1-2 Frequency Spectrum for 1 kHz Square wave

Fig. 2.1-3 shows the frequency spectrum of 1 kHz sawtooth wave. A sawtooth wave is composed of a fundamental sine wave and an infinite number of odd and even harmonics. The odd and even harmonics of the sawtooth wave with exponentially decreasing amplitude are indicated at 1 kHz apart along the horizontal axis.

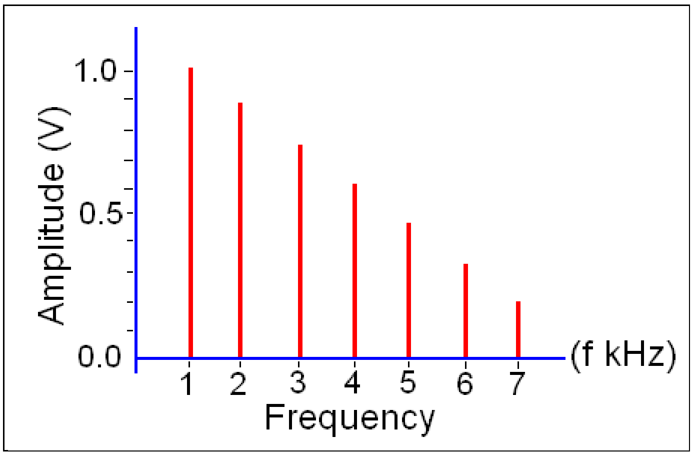


Fig. 2 1-3 Frequency Spectrum for 1 kHz Sawtooth wave

AMPLITUDE MODULATION

In Amplitude Modulation, the amplitude of the Fixed Frequency Carrier is varied by the Modulating Signal. Fig. 2.1-4 shows the block diagram of the basic method of generating an AM waveform. The AM Modulator has two inputs, high frequency carrier (f_C) and modulating audio signal (f_m). The Modulator mixes the two input signals and generates an AM Output waveform, as shown.

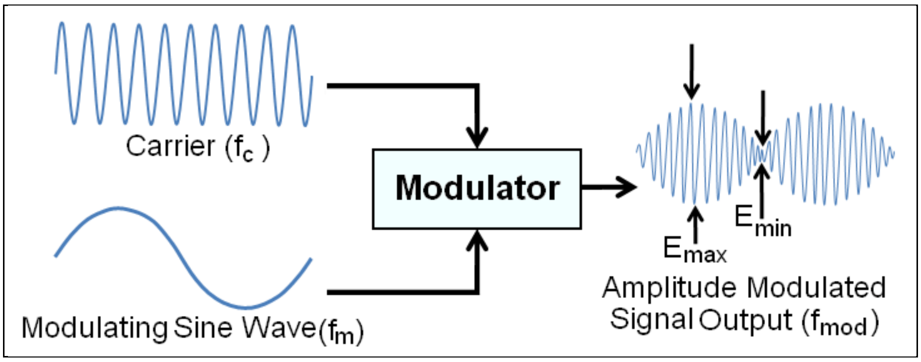


Fig. 2.1-4 Amplitude Modulation

The AM Modulated Output is called the Modulation Envelope having both positive and negative half cycles of the output waveform. The amplitude and frequency of the modulating signal determines the shape of the modulation envelope.

PERCENT MODULATION (%AM)

Percent Modulation is the degree of modulation that is defined as the Percent Ratio of the difference between the maximum and the minimum to the sum of the maximum and the minimum peak-to-peak modulated carrier and is measured in percentage. Percent AM Modulation is also known as Modulation Factor that varies from 0 to 1. Percent AM Modulation is given by the equation:

$$Percen\ Mode = \frac{\mathrm{E_{max}} - \mathrm{E_{min}}}{\mathrm{E_{max}} + \mathrm{E_{min}}} \times 100$$

An unmodulated AM carrier is said to be a Continuous Wave and has 0% modulation.

EXAMPLE 2.1-1

Given an unmodulated and AM modulated waveforms in Fig. 1-3(a, b, c).
Determine the % Modulation for each case.

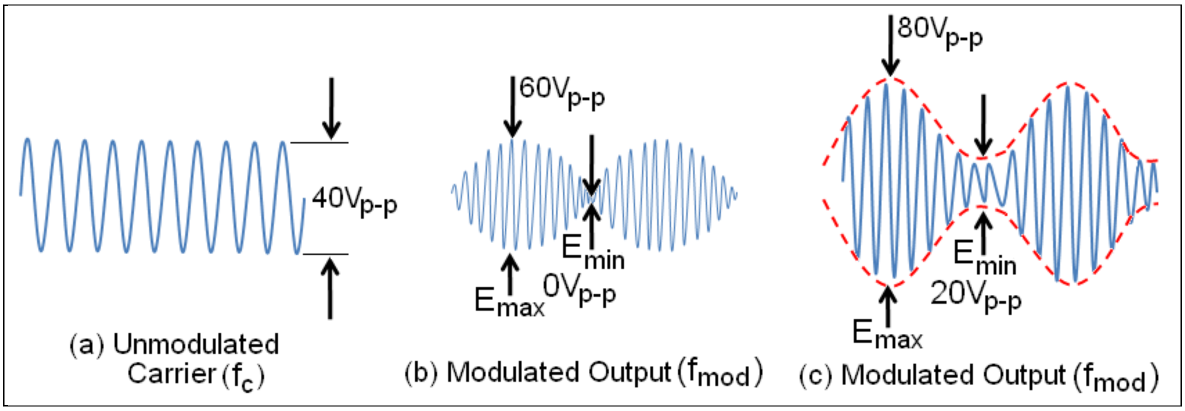


Fig. 2.1-5

SOLUTION

Fig. 2.1-5(a) shows an unmodulated carrier with amplitude signal:

$$E_{max} = E_{min} = 40V_{p-p}$$

Therefore,

$$Percent\ Mode = \frac{\mathrm{E_{max} - E_{min}}}{\mathrm{E_{max} + E_{min}}} \times 100 = \frac{40 - 40}{40 + 40} \times 100 = 0\%$$

Fig. 2.1-5(b) shows an AM modulated carrier with

$$E_{max} = 80V_{p-p}\ \&\ E_{min} = 0V_{p-p}$$

Therefore,

$$Percent\ Mode = \frac{\mathrm{E_{max} - E_{min}}}{\mathrm{E_{max} + E_{min}}} \times 100 = \frac{80 - 0}{80 + 0} \times 100 = 100\%$$

Fig. 2.1-5(c) shows an AM modulated carrier with

$$E_{max} = 60V_{p-p}\ \&\ E_{min} = 20V_{p-p}$$

Therefore,

$$Percent\ Mode = \frac{\mathrm{E_{max} - E_{min}}}{\mathrm{E_{max} + E_{min}}} \times 100 = \frac{60 - 20}{60 + 20} \times 100 = 50\%$$

UNDER MODULATION

Under modulation is caused by too low % Modulation, when E_{min} is too high, Low amplitude modulating signal normally results in low % modulation. Too low modulating signal or too high level of carrier can cause Under modulation. Since AM Receiver recovers only the modulating signal, a low amplitude-modulating signal will result in a low volume audio, when demodulated. Fig. 2.1-5(c) shows an under modulated output of a transmitter that has lower % modulation of only 50%.

OVER MODULATION

Over modulation is caused by too high amplitude of modulating signal and resulting in carrier cut off at the transmitter and audio clipping at the receiver. Too high amplitude of modulating signal will result in clipped audio with severe distortion, or a corresponding loss of data, when demodulated by the receiver. Fig. 2.1-6(a) and (b) shows the over modulating signal and the carrier, respectively.
Fig. 2.1-6(c) shows an over modulated output of a transmitter with RF completely turned off around negative peak of the modulating signal. Fig. 2.1-6(d) shows the detected AM signal at the receiver with clipped negative half cycle audio causing severe distortion.

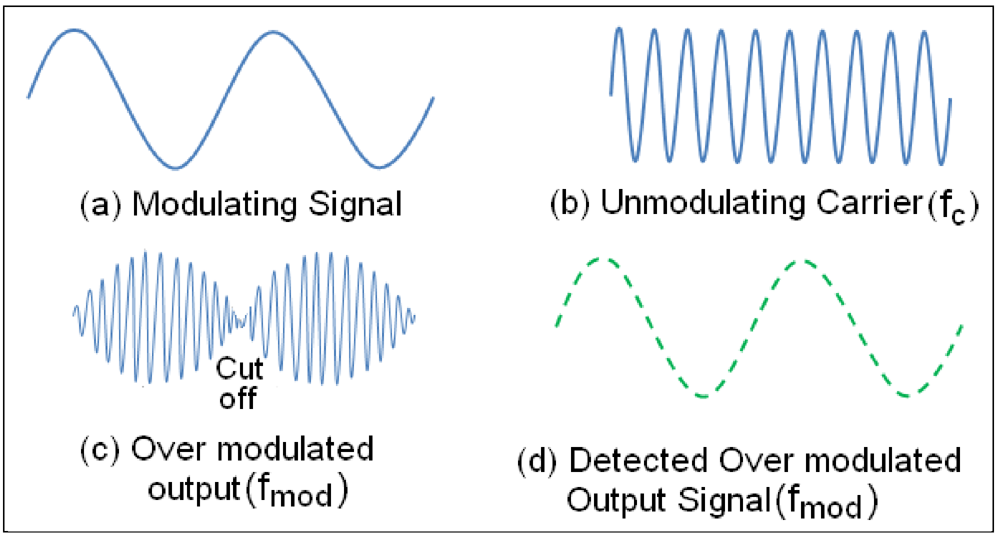


Fig. 2.1-6 Over Modulation

AM SIDEBANDS

An AM wave is a representation of the audio signal with which the carrier is modulated. The modulated wave consists of a carrier frequency that varies in amplitude proportional to the amplitude and frequency of the modulating signal. An AM modulated wave is a complex wave that contains two other frequencies and the carrier itself. The other two frequencies are carrier plus the modulating frequency (f_C + fm), and carrier minus modulating frequency ($f_c - f_m$). The other two frequencies present in the modulated wave are created by the non-linear action of the modulator and are called the Sidebands. The intelligence is contained in the AM sidebands.
The AM wave has no modulating signal frequency, although it does represent the modulating signal. The three frequency components of an AM signal, therefore, are:

- Carrier frequency
- Upper sideband
- Lower sideband.

UPPER SIDE BAND

The Upper Side band frequency (f_H) is calculated by adding the carrier frequency (f_C) to the modulating frequency (f_m), as follows:

Upper Sideband, $f_H = f_c + f_m$

LOWER SIDEBAND

The lower Sideband frequency (f_L) is calculated by subtracting the modulating frequency (f_m) from the carrier frequency (f_C), as follows:
Lower Sideband, $f_L = f_c - f_m$. As the modulating frequency is increased, the sideband frequencies move farther apart from the carrier. Fig. 2.1-7 in the following example shows the frequency spectrum of the 1 MHz carrier modulated at 10 kHz, with two sidebands at 1.01 MHz and 0.99 MHz

EXAMPLE 2.1-2

Determine the upper and lower sidebands in an AM modulated wave with 1MHz carrier frequency and 10 kHz modulating frequency. Draw the frequency spectrum of modulated wave, showing the two sidebands in Fig. 2.1-7

SOLUTION

Upper Sideband

$$f_H = f_C + f_M = 1\text{MHz} + 10\text{kHz}$$
$$= 1.101 \text{ MHz}$$

Lower Sideband

$$f_H = f_C + f_M = 1\text{MHz} - 10\text{kHz}$$
$$= 0.99 \text{ MHz}$$

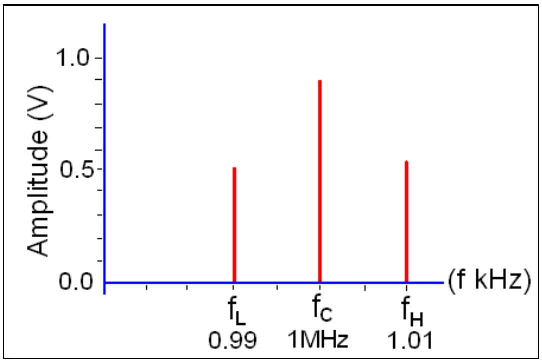


Fig. 2.1-7 AM Sidebands

AM BANDWIDTH (BW)

The bandwidth of an AM system extends from the lowest sideband to the highest sideband. Bandwidth is limited by the transmitter itself. The carrier itself contains no information or intelligence. The information is conveyed through the side bands that are created by the modulating signal.

As the intelligence is contained in the modulating signal in an AM system, both the carrier and the sidebands must be transmitted and received. The bandwidth is twice the highest modulating signal.

$$BW = 2 \times f_{m(max)}$$

Where: $BW = \text{Bandwidth}$

$f_{m(max)} = \text{the highest modulating frequency}$

EXAMPLE 2.1-3

Determine the bandwidth of an AM system with modulating frequency range of 50Hz to 15kHz.

SOLUTION

$f_{m(max)} = 15\text{kHz}$

Since $BW = 2 \times f_{m(max)}$, then; $BW = 2 \times 15\text{kHz} = 30\text{kHz}$

FREQUENCY MODULATION (FOR ANALOG TRANSMISSION)

In frequency modulation, the frequency of the Constant Amplitude Carrier is varied by the amplitude of the modulating signal. Fig. 2.1-8 shows a Frequency Modulated (FM) waveform. Fig. 2.1-8(a) is the modulating waveform and Fig. 2.1-8(b) is the center frequency to be modulated. The resulting modulated carrier is shown in Fig. 2.1-8(c). As shown in the modulated carrier, the carrier frequency is increasing, as the modulating signal is going positive. Alternately, the carrier frequency is decreasing, as the modulating signal is going negative. The frequency of the modulated carrier is maximum at the positive peak of the modulating signal and minimum at the negative peak of the modulating signal. Each time the modulating signal passes through 0V, the carrier returns to its center frequency. The carrier is equally shifted above and below its center frequency by the positive and negative half cycles of the modulating waveform, respectively. The numerous frequency shifts caused by the modulating signal generate additional frequencies, resulting in many upper and lower sidebands.

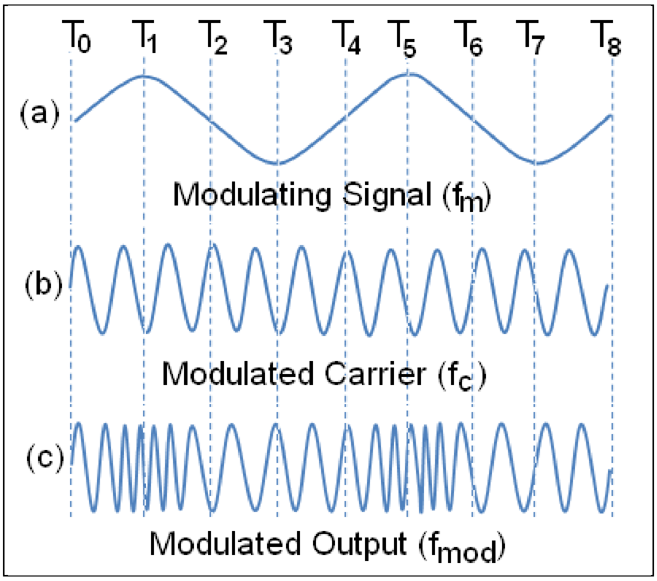


Fig. 2.1-8 Frequency Modulation

FREQUENCY DEVIATION

Frequency Deviation is the amount of shift in carrier, above and below the center frequency, caused by the modulating signal. The amount of carrier Deviation is directly proportional to the amplitude of the modulating signal. The rate of carrier deviation is the same as the modulating signal.

EXAMPLE 2.1-4

A 100MHz FM carrier is shifted from 99.9MHz to 100.1MHz, when modulated by a 1kHz tone. Determine the frequency deviation, f_d.

SOLUTION

F_C = 100MHz

$+f_d$ = (100.1 - 100) MHz = 0.1MHz = 100kHz

$-f_d$ = (99.9 - 100) = -0.1MHz = -100kHz

$f_d = \pm$ 100kHz

FM BANDWIDTH (BW)

The FM bandwidth is determined by twice the number of sidebands (fm) multiplied by the Modulating Frequency (fm).

$BW = 2 \times n \times f_m$ Where BW = Bandwidth

n = No. of sidebands

f_m = Modulating Frequency

The number of sidebands and their amplitude is determined by the Modulation Index table. The first-order sideband pair is determined by the addition and subtraction of the modulating frequency, similar to AM.

1st Upper Sideband Frequency = $f_C + f_m$

1st Lower Sideband Frequency = $f_C - f_m$

The second-order sideband pair frequency is determined by the addition and subtraction of twice the modulating frequency.

2nd Upper Sideband Frequency = $f_C + 2 \times fm$

2nd Lower Sideband Frequency = $f_C - 2 \times fm$

The nth-order sideband pair is determined by the addition and subtraction of n times the modulating frequency.

nth Upper Sideband Frequency = $f_C + n \times fm$

nth Lower Sideband Frequency = $f_C - n \times fm$

EXAMPLE 2.1-5

A 100kHz FM system has maximum carrier Frequency Deviation of 18kHz and Modulating Frequency of 3kHz. Determine:

a) Modulation index, m. $m = f_d/fm$

b) Number of sideband pairs

c) Frequency of each sideband pair nth sideband = $f_C \pm (n \times fm)$

d) Amplitude of the carrier and each sideband pair

e) Bandwidth, BW. $BW = 2 \times n \times fm$

f) Draw the Frequency Spectrum of the Modulated Wave in Fig. 2.1-9.

SOLUTION

a) $m = f_d/fm = 18kHz/3kHz = 6$
b) From Modulation Index table, the number of sidebands for Modulation Index of 6 is 9
c) Upper sideband frequencies

fH	f_C	f_C+fm	f_C+2fm	f_C+3fm	f_C+4fm	f_C+5fm	f_C+6fm	f_C+7fm	f_C+8fm	f_C+9fm
kHz	100	103	106	109	112	115	118	121	124	127

Lower sideband frequencies:

fL	f_C	f_C-fm	f_C-2fm	f_C-3fm	f_C-4fm	f_C-5fm	f_C-6fm	f_C-7fm	f_C-8fm	f_C-9fm
kHz	100	97	94	91	88	85	82	79	76	73

d) Amplitude:

A	0.15	-0.28	-0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02

e) BW = 2 × 9 × 3 = 54 kHz

Bessel functions

The carrier and sideband amplitudes are illustrated for different modulation indices of FM signals.
Based on the Bessel functions.

Modulation index	Carrier	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.00	1.00																
0.25	0.98	0.12															
0.5	0.94	0.24	0.03														
1.0	0.77	0.44	0.11	0.02													
1.5	0.51	0.56	0.23	0.06	0.01												
2.0	0.22	0.58	0.35	0.13	0.03												
2.41	0	0.52	0.43	0.20	0.06	0.02											
2.5	−.05	0.50	0.45	0.22	0.07	0.02	0.01										
3.0	−.26	0.34	0.49	0.31	0.13	0.04	0.01										
4.0	−.40	−.07	0.36	0.43	0.28	0.13	0.05	0.02									
5.0	−.18	−.33	0.05	0.36	0.39	0.26	0.13	0.05	0.02								
5.53	0	−.34	−.13	0.25	0.40	0.32	0.19	0.09	0.03	0.01							
6.0	0.15	−.28	−.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02							
7.0	0.30	0.00	−.30	−.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02						
8.0	0.17	0.23	−.11	−.29	−.10	0.19	0.34	0.32	0.22	0.13	0.06	0.03					
8.65	0	0.27	0.06	−.24	−.23	0.03	0.26	0.34	0.28	0.18	0.10	0.05	0.02				
9.0	−.09	0.25	0.14	−.18	−.27	−.06	0.20	0.33	0.31	0.21	0.12	0.06	0.03	0.01			
10.0	−.25	0.04	0.25	0.06	−.22	−.23	−.01	0.22	0.32	0.29	0.21	0.12	0.06	0.03	0.01		
12.0	0.05	−.22	−.08	0.20	0.18	−.07	−.24	−.17	0.05	0.23	0.30	0.27	0.20	0.12	0.07	0.03	0.01

Table 2.1-2 Modulation Index

f) Draw the Frequency Spectrum of the Modulated Wave in Fig. 1-7.

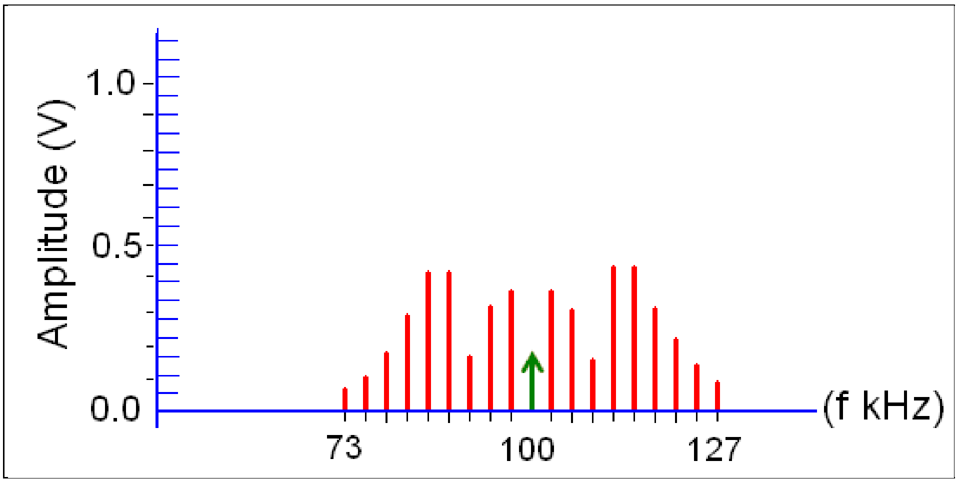


Fig. 2.1-9 Frequency Spectrum of 100 kHz FM System

PRINCIPLE OF FREQUENCY SHIFT KEYING MODEM

MODEM is defined as Modulator and Demodulator sections of the transmitter and receiver used for voice and data transmission and reception, respectively. The transmission medium may be a telephone line at 48-52VDC or high voltage power line at 69-327kV, or RF microwave. Frequency Shift Keying (FSK) is based on shifting the carrier frequency of a blocking oscillator above and below the center frequency when data logic 1 and 0 levels are applied to the input. Modems at both transmitting and receiving ends are equipped with similar transmitters and receivers.

As shown in Fig. 2.1-10, the transmitting Modem sends signal in F_1 band that is comprised of 1270Hz as logic 1 frequency (f_m) and 1070Hz as logic 0 frequency (f_S) with blocking oscillator tuned to 1170Hz. The receiver filter circuit at the receiving end modem is tuned to the resonant frequency of 1170Hz with a frequency deviation (Δf) of 200Hz to receive in F_1 band.

The receiving modem transmits signal in F_2 band that is comprised of 2225Hz as logic 1 frequency and 2025Hz as logic 0 frequency with blocking oscillator tuned to 2125Hz. The receiver filter circuit at the transmitting end modem is tuned to the resonant frequency of 2125Hz with a frequency deviation (Δf) of 200Hz to receive in F_2 band. The two distinct frequencies in both F_1 and F_2 bands for binary logic 1 and 0 are called the mark and space frequencies, respectively. F_1 and F_2 bands in both modems are necessary for Full-Duplex communication.

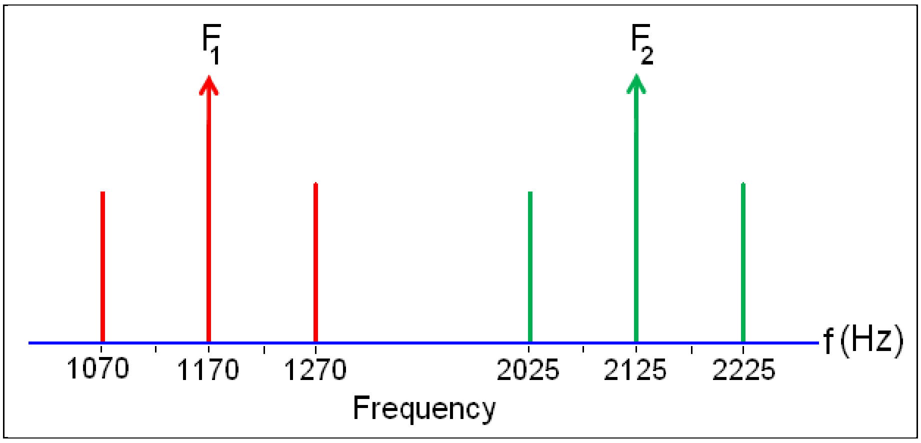


Fig. 2.1-10 Frequency Shift Keying Application in Modem

When there is no input signal to the modulator, the oscillator in the modulator section oscillates at a fixed center carrier frequency (f_C = 1170Hz). In F_1 band transmission for logic 1 (mark), the blocking oscillator frequency shifts 100Hz above the center frequency from 1170Hz to 1270Hz (f_{mark}). In F_1 band transmission for logic 0 (space), the blocking oscillator frequency shifts 100Hz below the center frequency from 1170Hz to 1070Hz (f_{space}). Similarly, in F_2 band reception for logic 1 (mark), the blocking oscillator frequency shifts 100Hz above the center frequency from 2125Hz to 2225Hz (f_{mark}). In F_2 band reception for logic 0 (space), the blocking oscillator frequency shifts 100Hz below the center frequency from 2125Hz to 2025Hz (f_{space}).

TCF-10 FREQUENCY-SHIFT TRANSMITTER APPLICATION

The TCF-10 Frequency-Shift Transmitter provides the transmission of any of the two closely controlled discrete frequencies, within a narrow band channel, over the HV transmission lines. The center frequency of the channel can vary between 30-300kHz in 0.5kHz steps. Assuming TCF-10 carrier frequency (f_C) of 150kHz, Fig. 2.1-11.

the two frequencies transmitted are separated by ($\pm\Delta f = \pm 100$ Hz), one being at (f_C + 100Hz = 150.1 kHz) and the others at (f_C – 100 Hz = 149.9 kHz).

The higher frequency, termed as the Guard Frequency, is transmitted continuously when conditions are normal. The Guard frequency indicates at the receiving end of the line that the channel is operating normal that prevents false operation of the receiver due to line noise. The lower frequency, termed as the Trip Frequency, is transmitted as

a signal that an operation, such as tripping circuit breaker, should be performed at the receiving end of the line.

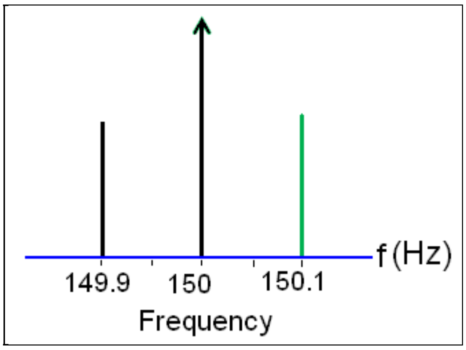


Fig. 2.1-11 Frequency Shift Keying Application in TCF-10 Transmitter

FIBER OPTIC COMMUNICATION FUNDAMENTALS

The latest Telecommunications technology uses light passing through Fiber Optic cables, Fig. 2.1-12, to carry audio, video, and data signals around the world.

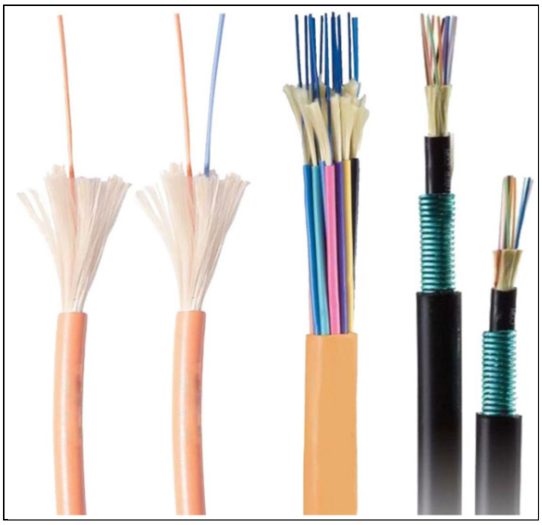


Fig. 2.1-12 Fiber Optic Cable

Fiber optics is a field of technology that uses thin, flexible, transparent fibers to carry light. Fiber Optics combine the use of light, optics, and electronics to transfer information from one point to another. The transparent fibers, called Optical Fibers, are made of glass or plastic. Light enters one end of the fiber, travels the length of the

fiber, and exits the opposite end. The light that passes through an Optical Fiber, sometimes called a Light Pipe, has many uses. An Optical Fiber is used for transmitting digital, audio, and video signals. It is also used for projecting images, remote sensing, and indicating.

ADVANTAGES OF FIBER OPTICS

Fiber Optic cables may consist of several optical fibers and have many advantages over using copper-wire cables. Several advantages of fiber optics are:

1. Wide Bandwidth - Optical fiber can handle signals up to 1 T-Hz (Tera-Hertz), which allows high speed data transfers up to 10 Gbps (625,000 pages of text per second, or 65,000 simultaneous telephone conversations over one fiber). Higher the bandwidth, more the frequency channels that can be accommodated on the same Optical fiber.
2. Low Loss - The small signal loss in optical fiber allows the use of fewer repeaters.
3. EMI Immunity - Optical fiber is unaffected by electromagnetic fields, such as Electro-Magnetic Interference (EMI) or Radio Frequency Interference (RFI).
4. Light Weight - Optical fiber is up to nine times lighter and, therefore, is invaluable to the aircraft industry.
5. Small Size - Optical fiber allows space savings in aircraft and submarines.
6. Safety - Optical fiber does not create electrical fire hazards and does not attract lightning.
7. Security - Optical fiber does not radiate energy, so illegal eavesdropping is extremely difficult.
8. Ruggedness - Glass fiber is corrosion resistant.

SAFETY PRECAUTIONS

When handling Fiber Optic cables, you should keep several personal Safety Precautions in mind, as follows:

- Never look directly into the end of an optical fiber.
  The light source could be a laser, or laser LED, which can actually burn living tissue inside the eyes and permanently blind you. Often, you cannot be certain that the light source is not a laser type, or that the light source is turned off.
- Never deliberately break a glass Optical Fiber without properly protecting the eyes and skin.

Glass splinters that are smaller in diameter than a human hair can puncture the skin and become embedded.

FIBER OPTIC COMMUNICATION LINK

As shown in Fig. 2.1-13, Fiber Optic Communication Link consists of a Fiber Optic cable connecting the output of a Fiber Optic Transmitter to the input of a Fiber Optic Receiver: The voice or data to be transmitted is applied to the input of the Fiber Optic Transmitter Driver Circuit. The Driver Circuit drives an Infra Red (IR) LED Light Source located at the optical connector, so that the light is coupled to the Fiber Optic cable. The received voice or data at the other end of the Fiber Optic cable is applied to the input of the Fiber Optic Receiver Detector Circuit through an optical connector.
The output of the Light Detector is connected to the Output Circuit and the received signal is available at the output circuit.

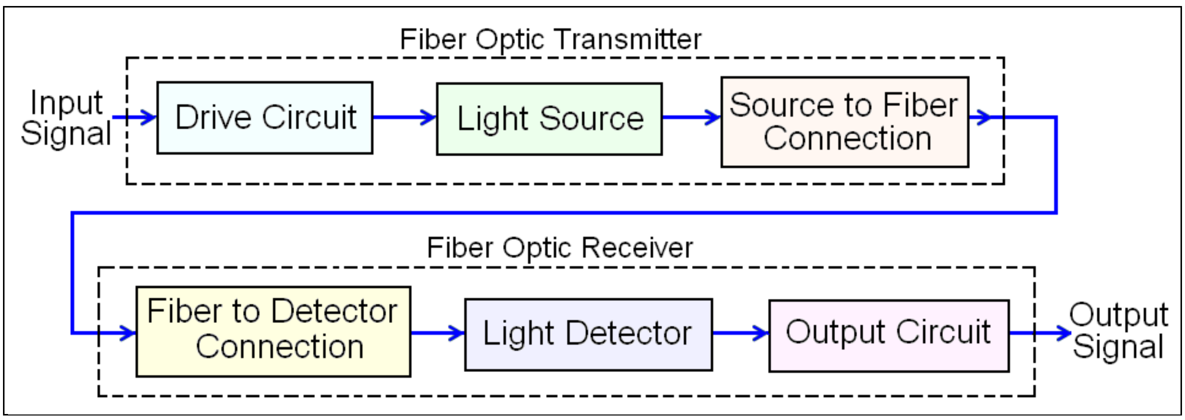


Fig. 2.1-13 Fiber Optic Communication Link

SUMMARY

- Communication is defined as the process of transferring information.
- Information is defined as the knowledge or intelligence in terms of analog or digital data to be transferred.
- Carrier frequency is a standard fixed or variable high frequency sine wave.
- Modulator modulates or mixes the carrier with the analog or digital information signal to be transmitted.
- Demodulator demodulates or recovers the analog or digital information signal from the received carrier.
- Modulating signal is the information signal, voice, or digital data, modulating the carrier.
- The media available for transmission of information are wire/Cable/Power Line Carrier, Space (RF), and Fiber Optic.
- The Radio Frequency Spectrum consists of a Range of Frequencies between 3kHz and 300GHz.
- In VHF band, the TV CHANNELS (CH2 - CH6) range is 54MHz - 88MHz.
- In VHF band, the FM frequency range is 88MHz - 108MHz.
- In VHF band, the TV Channels (CH7 - CH13) range is 174MHz - 216MHz.
- In UHF band, the TV Channels (CH14 - CH83) range is 470MHz - 890MHz.
- Time Domain Analysis is used for signals that vary with time, such as a sine wave, a square wave, or a triangular wave displayed on an oscilloscope.
- A pure sine wave has no other frequency components, as observed on an oscilloscope.
- A square wave consists of an infinite number of odd-order harmonics added and subtracted from the fundamental wave.
- Frequency Domain Analysis is used for signals that vary with frequency, for the study of RF Modulation.
- The three basic types of Modulation are Amplitude, Frequency, and Phase Modulation.

- In Frequency Modulation, the frequency of the Constant Amplitude Carrier is varied by the Amplitude of the Modulating Signal.
- Frequency Deviation is the amount of shift in carrier, above and below the center frequency, caused by the modulating signal.
- The amount of Carrier Deviation is directly proportional to the Amplitude of the Modulating Signal.
- The Fiber Optic Receiver and Fiber Optic Transmitter can be used for analog or digital communication links.
- The light that passes through an Optical Fiber, sometimes called a Light Pipe.

GLOSSARY

Communication:	Transferring information
Information:	Message in voice or data.
Carrier:	A high Frequency Wave that is modulated by the Modulating Signal.
Modulation:	Mixing data wave with carrier wave
Modulated Carrier:	Messenger wave carrying information message
Transmission Medium:	Path or means of transmission
Demodulator:	Detector/Receiver.
RF:	Radio Frequency
AM:	Amplitude Modulation
FM:	Frequency Modulation
Harmonic:	Multiples of basic frequency
Frequency Domain:	Uniform orientation of Amplitude versus Frequency display
Spectrum:	Range of frequencies in group
BW:	Bandwidth beyond which the information cannot be transmitted or received
Frequency Deviation:	The amount of shift in carrier above and below the carrier
Modulation Index:	The ratio of frequency deviation to modulating signal
Modem:	Modulator and Demodulator
FSK:	Frequency Shift Keying
Data Link:	A communication link that allows the transfer of digital data

REVIEW EXERCISE

ANSWER THE FOLLOWING QUESTIONS

ANALOG COMMUNICATIONS

1. Communication is the process of transferring ____ in terms of _____ or _____.
2. Information is defined as _______ and _______ contained in ______ or _____.
3. The media available for transmission of information are:
   ___________________, ___________________, and ___________________
4. Define the following, as used in international frequency spectrum chart.
   VLF: ____
   LF: ____
   MF: ____
   HF: ____
   VHF: ____
   UHF: ____

TYPES OF MODULATION

1. Any waveform displayed on an oscilloscope, is in ___________ domain.
2. Any Complex Waveform is composed of many ___________ waves.
3. A square wave is composed of a _______________ sine wave and a __________ number of ________________ harmonics.
4. A Harmonic is another frequency component of the Fundamental Wave that is an integral multiple of the fundamental wave. True or False.
5. A sawtooth wave is composed of a _______________ sine wave and a __________ number of ______ and __________ harmonics.
6. The frequency spectrum analyzer is used to study the _____ ____________ in ____________ domain.
7. The First Harmonic is the _____________ _______ and has __________ amplitude on the Spectrum Analyzer.

AMPLITUDE MODULATION

1. Which characteristic of the sine wave carrier is varied in an AM system:

a)	Frequency	b)	Amplitude
c)	Phase Angle	d)	All of above

2. Which characteristic of the sine wave carrier is varied in an FM system:

a)	Frequency	b)	Amplitude
c)	Phase Angle	d)	Both (a) and (c)

3. The two major types of Modulation used for Analog Transmission are:

a)	Frequency Modulation	b)	Phase Modulation
c)	Amplitude Modulation	d)	Both (a) and (c)

4. An AM Modulator mixes, which two input signals:
   a) The modulated carrier and the modulating signal
   b) The modulated output and the high frequency carrier
   c) The high frequency carrier and the modulating signal
   d) The low frequency carrier and the modulating signal

5. Percent AM modulation is known as _______________________.

6. The AM Modulation Factor varies from:

a)	0 to 100	b)	0 to 10
c)	10 to 100	d)	0 to 1

7. The Percent Modulation of an unmodulated carrier is:

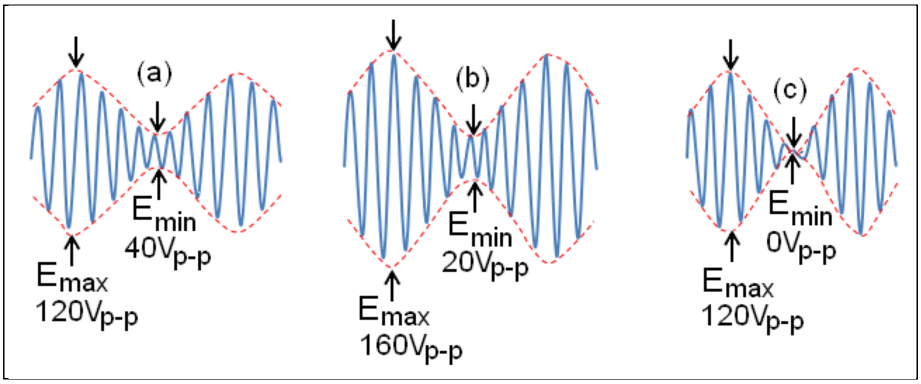
a)	0%	b)	10%
c)	100%	d)	None of above

8. Under modulation is caused by:

a)	High carrier level	b)	High amplitude modulating signal
c)	Very low amplitude modulating signal	d)	Both (a) and (c)

9. Given an AM modulated waveforms, Determine the % Modulation for each:

$$Percent\ Mod = \frac{\mathrm{E_{max}} - \mathrm{E_{mix}}}{\mathrm{E_{max}} + \mathrm{E_{mix}}} \times 100\%$$



10. Over modulation is caused by:

a) Very low carrier level
b) Very high amplitude modulating signal
c) Very low amplitude modulating signal
d) Both (a) and (b)

11. How many sidebands are there in an AM modulated wave:

a) Infinite
b) 1
c) 2
d) 4

12. The upper and lower sideband frequencies in a 100kHz AM wave with 10kHz modulating signal are:

a) 100kHz and 10kHz
b) 110kHz and 90kHz
c) 120kHz and 80kHz
d) 110kHz and 80kHz

13. The intelligence is contained in the infinite number of AM sidebands.

True or False

14. The bandwidth of an AM signal at the highest modulating frequency of 20kHz is:

a) 20kHz
b) 10kHz
c) 40kHz
d) 80kHz

FREQUENCY MODULATION

1. Which characteristic of the sine wave carrier is varied in an FM system:

   a) Frequency b) Amplitude

   c) Phase Angle d) Both (a) and (c)

2. The three characteristics of Frequency Modulation are:

   ____

   ____

   ____

COMPLETE THE FOLLOWING STATEMENTS:

3. FM carrier frequency is maximum at the ________ peak of the modulating signal.
4. FM carrier frequency is minimum at the _________ peak of the modulating signal.
5. In FM, the maximum deviation occurs at the _________ and _________ peaks of the modulating signal.

6. The Frequency Deviation in an FM system is 50kHz. The Modulation Index at 10kHz modulating frequency is: $m = f_d/fm$

   a) 50 b) 10

   c) 5 d) 0.2

FIBER OPTIC COMMUNICATION FUNDAMENTALS

1. An Optical Fiber is used for transmitting ______, ______, and ______ signals.

2. The Optical Fibers are made of _____ or ______.

   a) Glass & Plastic b) glass & Chromium

   c) Aluminum & plastic d) Copper & plastic

3. List at least four advantages of fiber optics:

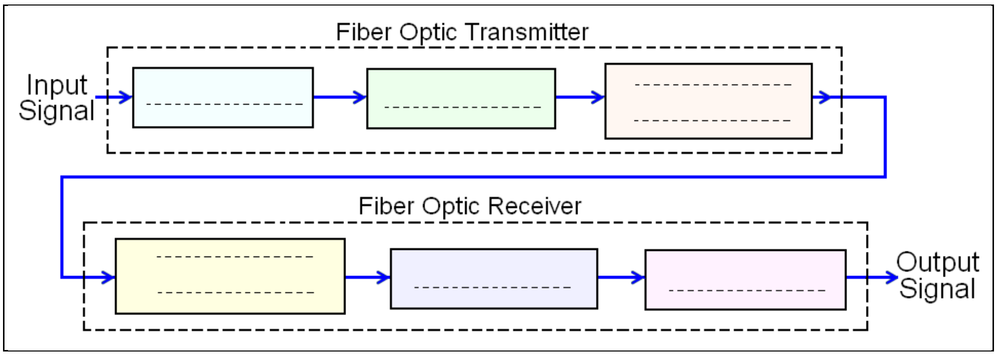
   ___________________________ ___________________________

   ___________________________ ___________________________

4. Laser light source is more dangerous to eyes than an IR light source, if viewed in directly. True or False

5. The received voice or data is applied to the input of the Fiber Optic _______ in Receiver through an optical connector.
   a) LED b) Detector
   c) Cable d) none of above

6. Identify the major function blocks in the Fiber Optic Communication Link, of the following diagram.



LESSON 2.2

APPLICATIONS OF FILTERS USED IN COMMUNICATION SYSTEMS

LESSON 2.2
APPLICATIONS OF FILTERS USED IN COMMUNICATION SYSTEMS

OVERVIEW

This lesson reviews the Low-Pass, High-Pass, Band-Pass and Band-Stop Filters used in audio and RF applications.

OBJECTIVES

On completion of this lesson, the trainee should be able to:

- Define a frequency filter and give some applications of filters.
- List two main classifications of filters.
- Draw the frequency response curve of a typical narrow band tuned amplifier and a wide band amplifier.
- Explain the Gain Roll-Off of a filter and its relationship to frequency.
- Define single-pole and multi-pole roll-offs.
- Explain the Figure of Merit or Quality factor **(Q)** of a filter.
- Describe the operation of a typical active filter.
- List basic types of Filters and explain the operation of each type.
- Draw the frequency response curves of different types of filters.
- Calculate the resonant frequency and bandwidth of a filter.
- Explain troubleshooting concepts of Active filters.

INTRODUCTION

Active Filters in one of their forms are Tuned Differential Operational Amplifier (op-amp) circuits designed in conjunction with resistors and capacitors for a certain bandwidth and are generally AC coupled, unlike DC coupled amplifiers for wide band applications. Filters as Tuned Amplifiers are extensively used in communication systems for filtering Audio and Video signals. And in other applications.

In Audio applications, tuned filters are used to separate high-frequency audio from low-frequency audio signals. For instance, three bandpass filters are used in a three-band Graphic Equalizer of an audio amplifier. Bandpass and Notch filters are used in noisy industrial environment. Notch filters and high-pass filters can be used to eliminate the low-frequency noise that can be generated in many audio systems.

For example, a Notch filter can be used to eliminate the 30Hz rumbling noise that can be produced by a turntable. By tuning the Notch filter to 30Hz, this noise will be blocked by filter, while the high audio frequencies are allowed to pass. Another application would be the use of a high-pass filter to eliminate both the 30Hz rumble and the 60Hz power line noise. By tuning the high-pass filter so that it has a lower cutoff frequency above 60 Hz, both the power line noise and the turntable noise are eliminated with a single circuit. The filters are classified as:

- Active Filters (Tuned Amplifiers)
- Passive Filters

ACTIVE FILTERS (TUNED AMPLIFIER)

Tuned Amplifier is designed to have a specific **Bandwidth** and would amplify or attenuate only those frequencies that are within its bandwidth range. Active Filters are very **versatile** and **stable** in tuning for a certain frequency response and can be constructed very **economically** in narrow band applications.

PASSIVE FILTERS

Passive Filters consist of passive components, such as inductors, capacitors, and resistors. Passive Filters are generally bulky and expensive, such as the ones used in Power Line Filtering.

DECIBEL (dB)

A Decibel is defined as the logarithmic ratio of the output to input signal (Gain) multiplied by 20. In other words, the Gain of a tuned amplifier is measured in Decibels (dB):

$$A_V = 20\log\frac{V_0}{V_{in}}\ dB$$

TUNED AMPLIFIER FREQUENCY RESPONSE

Fig. 2.2-1 shows the frequency response curve of a narrow band tuned amplifier and that of a standard wide band DC coupled amplifier.

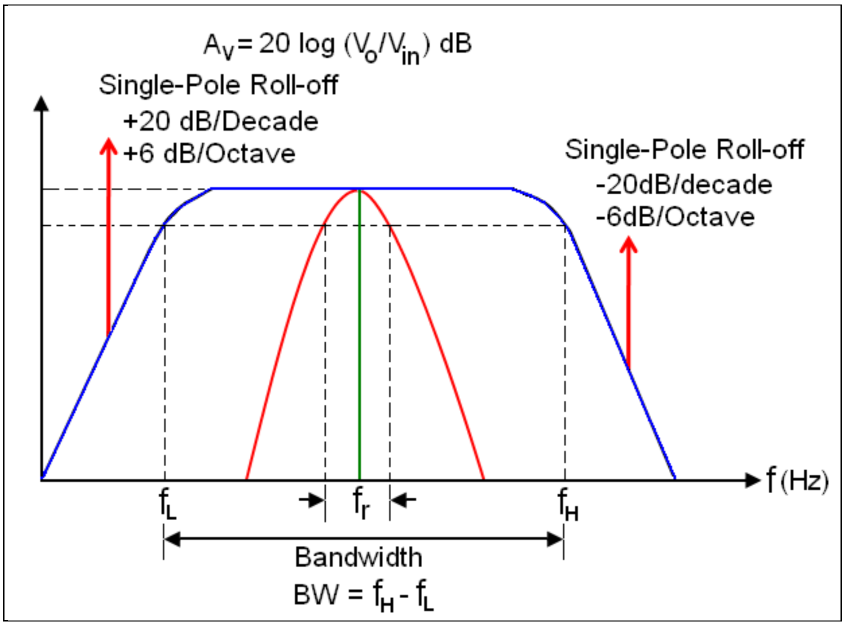


Fig. 2.2-1 Frequency Response Curve of a Tuned Amplifier

QUALITY FACTOR (Q) AND RESONANT FREQUENCY (f_r)

The Figure of Quality factor (Q) of a filter is the ratio of the resonant frequency (f_r) to the Bandwidth (BW) of the filter and is given by:

$$Q = \frac{f_r}{BW}$$

The range of frequencies that are considered to be passed by a filter is called the Bandwidth. The lower the bandwidth, the greater is the Quality factor, as required in Tuned-RF circuits. A filter with $Q > 10$ is called the narrow bandwidth filter and that with $Q < 10$ is called the wide bandwidth filter. In other words, wider bandwidth of a tuned amplifier results in a poor filter quality giving lower Q.

EXAMPLE 2.2-1

Given the filter Response Curve in Fig. 2.2-1, where f_r = 100 kHz, f_H = 1020 kHz, and f_L = 980 kHz. Determine:

a) The Bandwidth (BW) of the filter. ($BW = f_H - f_L$)
b) Quality factor (Q) of the filter. ($Q = fr/BW$)
c) Is it a narrow or wide bandwidth filter and Why?

SOLUTION

a) $BW = f_H - f_L$ = 1020kHz – 980 kHz = 40 kHz
b) $Q = f_r/ BW$ = 100kHz/40kHz = 25
c) It is a narrow bandwidth filter "Because Q > 10".

TYPICAL ACTIVE FILTER

Fig. 2.2-2 illustrates the principle of an active filter. When used with one or more op-amps, the response curve of an RC filter can be made as sharp as that of a good LC filter. The active filter is particularly handy at low frequencies. At low frequencies,

LC filters are often impractical because of the large size of the inductor required. When capacitors are added to the input or feedback circuit, we must consider the resulting impedance as shown. The voltage gain of the active filter is determined by the ratio of the feedback impedance (Z_2) to the input impedance (Z_1).

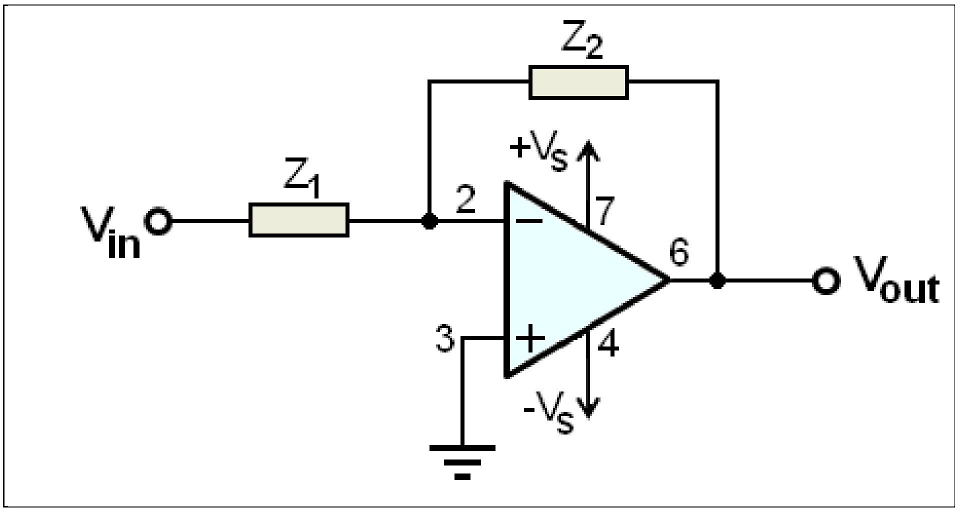


Fig. 2.2-2 Typical Active Filter

$$A_V = \frac{V_o}{V_{in}} = \frac{Z_2}{Z_1} = \frac{R_2 + jX_2}{R_1 + jX_1}$$

Where Z_1 & Z_2 include of R, L & C components. Since the impedance of an RC network varies with frequency, the gain of the stage also changes with frequency.

TYPES OF FILTERS

The four basic types of Filters are:

- Low-Pass Filter (LPF)
- High-Pass Filter (HPF)
- Band-Pass Filter (BPF)
- Band-Stop (Rejection) Filter (BSF)

SINGLE-POLE LOW-PASS ACTIVE FILTER

As shown in Fig. 2.2-3, a Low-Pass Filter passes all low frequencies below the cut-off frequency (fC2) and blocks all high frequencies above the cut-off. A single-pole roll-off is the slope of the voltage gain decreasing after higher cutoff frequency (fC2) at -20dB/Decade or -6dB/Octave, using a single capacitor and resistor. That is, when the frequency is increased ten times above the higher cutoff, the gain drops by 20dB/Decade and so on.

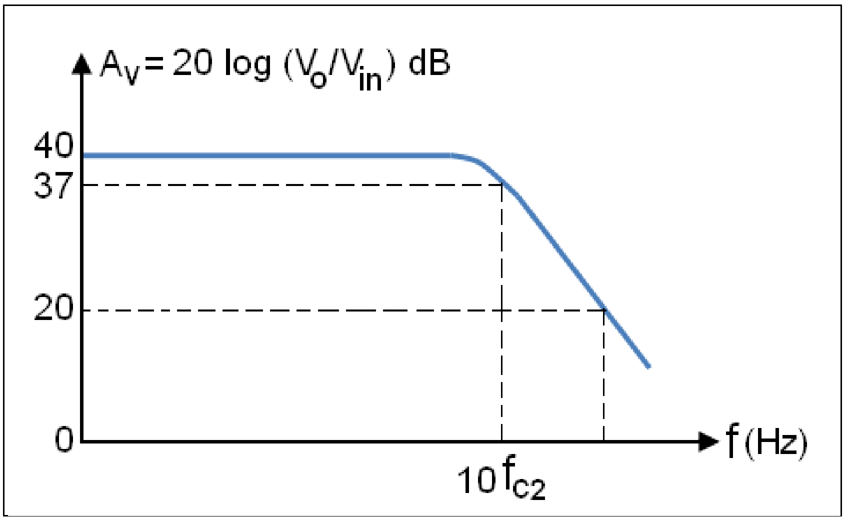


Fig.2 2-3 Single-Pole Low-Pass Filter

As shown in Fig. 2.2-4, the input signal is applied to the inverting terminal (-) through the input resistor R. The capacitor C is in the feedback circuit from output to the inverting input terminal. As the capacitor is a frequency dependent component, the tuned op-amp is a Low-Pass Filter (LPF). That is, the op-amp voltage gain stays constant at low frequencies to DC. The voltage gain starts dropping as the frequency is increased above the cutoff point, as shown in Fig. 2.2-2. The capacitive reactance (X_C) offered by the capacitor is dependent on the frequency of the input signal.

Capacitive reactance, $X_C = 1/(2\pi fC)$.

As the frequency is increased, the capacitive reactance decreases resulting in lower voltage gain. If the frequency is increased to infinity, the capacitive reactance is reduced to 0Ω for minimum gain.

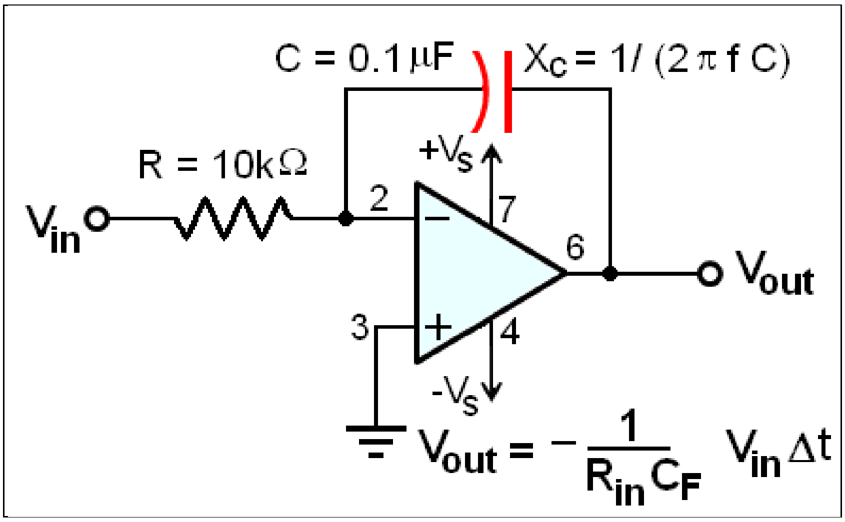


Fig. 2.2-4 Inverting Single-Pole Low-Pass Active Filter

Assuming an ideal op-amp having negligible bias currents, IB_1 and IB_2. Since the non-inverting input resistor R is grounded, the bias current $IB_2 = 0$ and the voltage V_X at the non-inverting (+) terminal is 0V. This V_X is present as virtual ground at inverting terminal (-). Assuming the current I1 flowing through R_1 in the direction shown, I_1 is given by:

$$I_1 = \frac{V_{in} + V_X}{R} = \frac{V_{in} + 0}{R} = \frac{V_{in}}{R}$$

Since $R_3 = R$ is grounded, the bias current $IB_2 = 0$ and the voltage at the non-inverting (+) terminal $V_X = 0V$, so that the voltage at the inverting terminal (-) is also 0V. The two equal input resistors (R) are used to keep the input offset current to a minimum.

Assuming positive-going signal, when an input signal voltage (V_{in}) is applied at the input terminal, the input current I_1 flowing through R is given by:

$$I_1 = \frac{V_{in}}{R}$$

When $IB_1 = 0$ for an ideal op-amp, I_1 can only flow through the feedback capacitor C into the output terminal, so that:

$$I_2 = I_1 = \frac{V_{in}}{R}$$

The direction of current I_2 indicates that the instantaneous value of output voltage V_O is of opposite polarity (180°) with respect to V_X, so that:

$$\mathrm{V_O = V_X - I_2\,X_C = 0 - I_1\left(\frac{1}{2\pi fC}\right) = -\left(\frac{V_{in}}{R}\right)\left(\frac{1}{2\pi fC}\right) = -\left(\frac{V_{in}}{2\pi fC}\right)}$$

The voltage gain at frequency (f) is given by:

$$A_V = \frac{V_O}{V_{in}} = -\frac{X_C}{R} = -\frac{1}{2\pi fC}$$

The negative sign indicates that the output voltage signal is at 180° out of phase with respect to the input signal. The output is fed back to negative input through the capacitor C, so that:

$$V_O = -\left(\frac{V_{in}}{2\pi fC}\right)$$

The cut-off frequency (f_{C2}) of the LPF is given by:

$$f_{C2} = \frac{1}{2\pi CR}$$

At the cut-off frequency, the output voltage is equal to approximately 70% of the input voltage:

$$V_O = \sqrt{2}\left(\frac{V_{P-P}}{2}\right) = 0.707 \times V_{P-P}$$

The cut-off frequency is inversely proportional to the resistor and the capacitor values. When fc_1 = 0Hz, the BW of LPF is simply:

$$B\,W_{LPF} = f_{C2} - f_{C1} = f_{C2}$$

It is standard practice to consider the cut-off frequency as the limit of the filter performance in terms of passing or rejecting frequencies.

$$\mathrm{V_{in} = -V_{in}\left(\frac{X_C}{R}\right) = (-2\ V_{P-P})\left(\frac{160\Omega}{10k\Omega}\right) = -32\ mV}$$

TWO-POLE LOW-PASS ACTIVE FILTER

As shown in Fig. 2.2-5, the two-pole LPF has -40dB/Decade or -12dB/Octave gain roll-off above the higher cut-off frequency (f_{C2}).

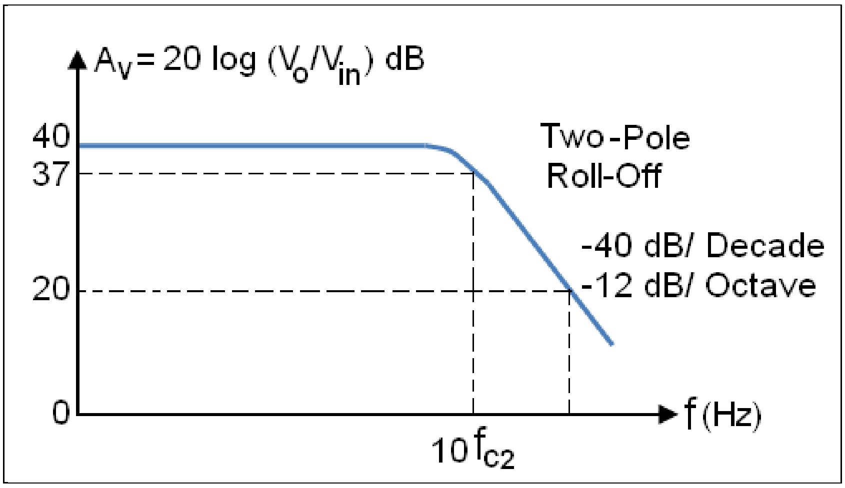


Fig. 2.2-5 Two-Pole Low-Pass Filter

Fig. 2.2-6 shows the Two-Pole Low-Pass Non-Inverting Active Filter that contains two RC components each contributing –20dB/Decade (-6dB/Octave) roll-off for a total of -40dB/Decade (-12dB/Octave).

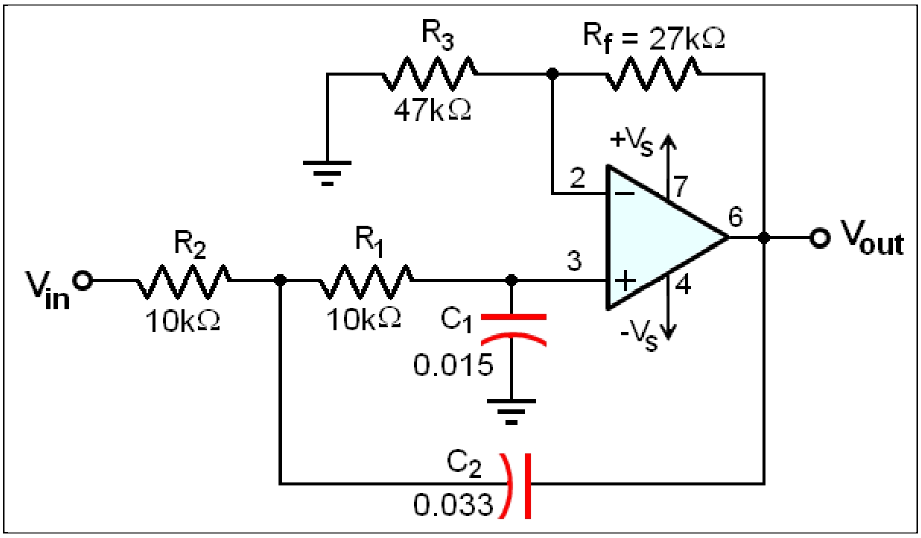


Fig. 2.2-6 Two-Pole Low-Pass Non-Inverting Active Filter

The Closed-Loop Gain (A_V) of the Active Filter is given by:

$$A_V = 1 + \frac{R_f}{R_3}$$

Also, $f_{C2} = \dfrac{1}{2\pi\sqrt{C_1 \times C_2 \times R_1 \times R_2}}$

EXAMPLE 2.2-2

Given the Two-Pole Non-Inverting LPF circuit, as shown in Fig. 2.2-7. Determine:

a) $BW_{LPF}\ f_{C2} = \dfrac{1}{2\pi\sqrt{C_1 \times C_2 \times R_1 \times R_2}}$

b) $A_V = 1 + \frac{R_f}{R_3}$

SOLUTION

a) $f_{C2} = \dfrac{1}{2\pi\sqrt{C_1 \times C_2 \times R_1 \times R_2}} = \dfrac{1}{2\pi\sqrt{(0.015\times10^{-6})(0.033\times10^{-6})(10k)(10k)}} = 715\text{Hz}$

b) $A_V = 1 + \frac{R_f}{R_3} = 1 + \frac{27k}{47k} = 1.57$

RL LOW-PASS FILTER

To illustrate low-pass filter action, Fig. 2.2-7 shows a specific series of measurements in which the frequency starts at zero (DC) and is increased in increments up to 20 kHz. At each value of frequency the output voltage is measured. The inductive reactance increases as frequency goes up, thus causing less voltage to be dropped across the resistor while the input voltage is held at a constant 10V throughout each step. The response curve for these particular values would appear the same as the response curve in Fig. 2.2-4 for the Single-Pole Low-Pass Active Filter.

$$X_L = 2\,\pi\,f_L$$

$$Z = R + jX_L = \sqrt{R^2 + {X_L}^2}$$

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$

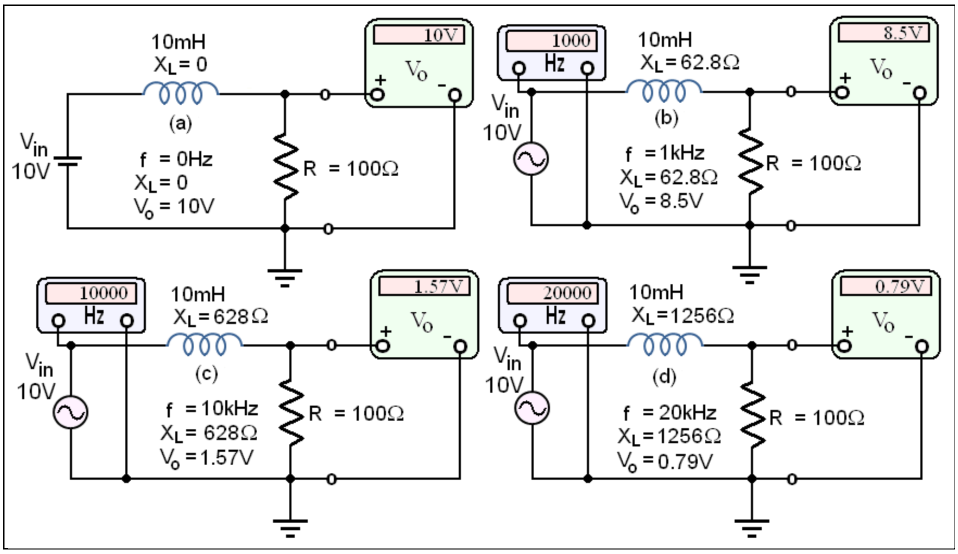


Fig. 2.2-7 LC Low-Pass Filter Action (winding resistance neglected)

SINGLE-POLE HIGH-PASS ACTIVE FILTER

As shown in Fig. 2.2-8, a High-Pass Filter passes all high frequencies above the cut-off frequency (f_{C1}) and blocks all low frequencies below the cut-off. A single-pole roll-off is the slope of the voltage gain decreasing below lower cutoff frequency (f_{C1}) at -20 dB/Decade or -6 dB/Octave, using a single capacitor and resistor. That is, when the frequency is decreased ten times below the lower cutoff, the gain drops by 20 dB/Decade and so on.

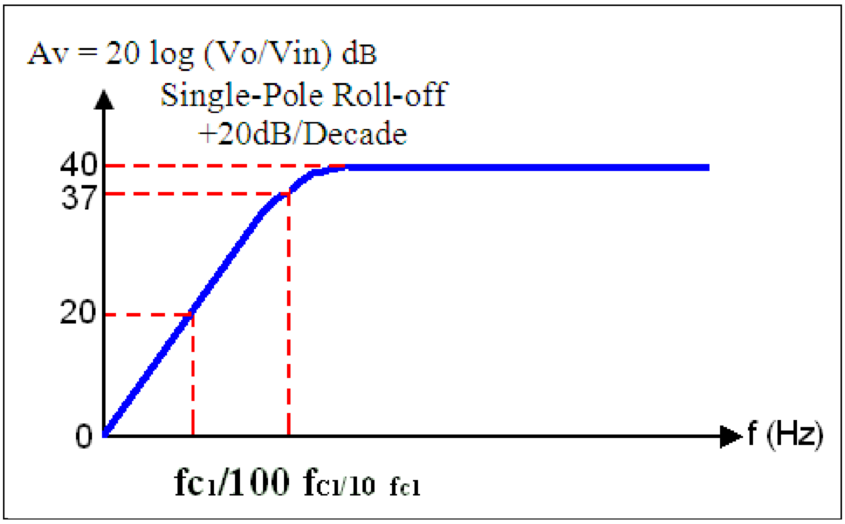


Fig. 2.2-8 Single-Pole High-Pass Filter

As shown in Fig. 2.2-9, the input signal is applied to the inverting terminal (-) through the input capacitor C. The resistor R is in the feedback circuit from output to the inverting input terminal. As the capacitor is a frequency dependent component, the tuned op-amp is a High-Pass Filter (HPF). That is, the op-amp voltage gain stays constant at higher frequencies above the cutoff. The voltage gain starts decreasing as the frequency is decreased below the cutoff point, Fig. 2.2-8.

The capacitive reactance (XC) offered by the capacitor is dependent on the frequency of the input signal.

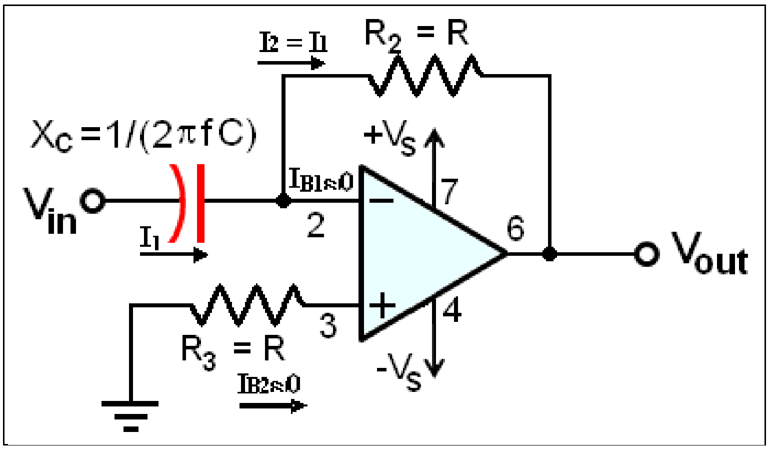


Fig. 2.2-9 Inverting Single-Pole High-Pass Active Filter

Assuming an ideal op-amp having negligible bias currents, I_{B1} and I_{B2}.

Since the non-inverting input resistor $R_3 = R$ is grounded, the bias current $I_{B2} = 0$ and the voltage V_X at the non-inverting (+) terminal is 0V. This V_X is present as virtual ground at inverting terminal. Assuming the current I_1 flowing through capacitor C in the direction shown, I_1 is given by:

$$I_1 = \frac{V_{in} - V_X}{X_C} = \frac{V_{in} - 0}{X_C} = \frac{V_{in}}{X_C}$$

Assuming positive-going signal, when an input voltage signal (Vin) is applied at the input terminal, the input current I_1 flowing through capacitor **C** is given by:

$I_1 = \frac{V_{in}}{X_C}$ where $X_C = \frac{1}{2\pi f_C}$

When $I_{B1} = 0$ for an ideal op-amp, I_1 can only flow through the feedback resistor $R_2 = R$ into the output terminal, so that:

$$I_2 = I_1 = \frac{V_{in}}{X_C}$$

The direction of current I_2 indicates that the instantaneous value of output voltage V_O is of opposite polarity (180°) with respect to V_X, so that:

$$V_O = V_X - I_2 R_2 = 0 - I_1 R_2 = -\left(\frac{2\pi f_C}{1}\right) R$$

The voltage gain of the differentiating circuit is given by:

$$A_V = \frac{V_O}{V_{in}} = -2\pi f_C R = -\frac{R}{X_C}$$

The negative sign indicates that the output voltage signal is at 180° out of phase with respect to the input signal. The cut-off frequency (f_{C1}) of the HPF is given by:

$$f_{C1} = \frac{1}{2\pi R C}$$

The cut-off frequency is inversely proportional to the resistor and the capacitor values. The output is fed back to negative input through the resistor $R_2 = R$, so that:

$$V_O = -V_{in} (2\pi f C R)$$

When $f_{C2} = \infty$Hz, the BW of HPF is ideally:

$$\text{BW HPF} = f_{C2} - f_{C1} = \infty - f_{C1} \approx \infty$$

As the higher cutoff (f_{C2}) in an active HPF is limited by the internal capacitances of the op-amp semiconductors, the BW is also limited to a finite value.

TWO-POLE HIGH PASS ACTIVE FILTER

A simple inverting two-pole high-pass filter is shown in Fig. 2.2-10. The input impedance (Z_{in}) and output impedance (Z_F) consist of RC networks. At low frequencies, the capacitive reactance of C_1 and C_2 are quite high. Therefore, Z_{in} is high at low frequencies.

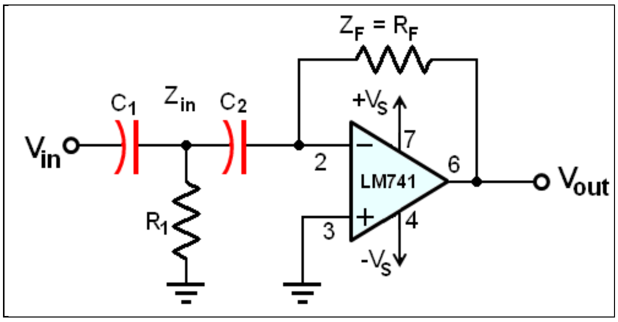


Fig. 2.2-10 Two-Pole High-Pass Active Filter

The gain is determined by: $A_V = {}^{Z_F}/_{Z_{in}}$

The feedback impedance Z_F is equal to R_F and is constant at all frequencies. Consequently, when Z_{in} is high, the gain is low resulting in low output (V_O) at low frequencies. As the frequency increases, the capacitive reactance of C_1 and C_2 decreases and therefore decreasing Z_{in}. As Z_{in} decreases, the gain (A_V) as well as V_O increase. The response curve of two-pole high-pass filter is shown in Fig. 2.2-11, indicating a steeper slope of the gain versus frequency. The effect of the two capacitors is to introduce two pole roll-off (20 dB + 20 dB = 40 dB).

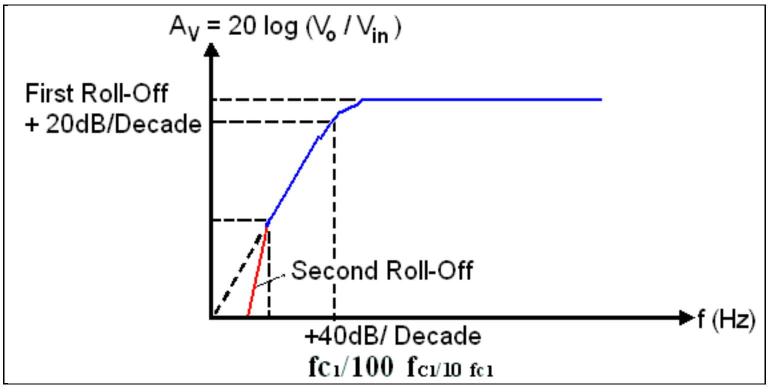


Fig. 2.2-11 Two-Pole High-Pass Filter Response curve

RL HIGH-PASS FILTER

To illustrate RL high-pass filter action, Fig. 2.2-12 shows a series of specific measurements. Again, the frequency starts at zero (DC) and is increased in increments up to 10 kHz. The inductive reactance increases as the frequency goes up, thus

causing more voltage to be dropped across the inductor. When the values are plotted, the response curve is the same as the one for the RC high-pass filter, as in Fig. 2.2-8.

CUT-OFF FREQUENCY OF RL HIGH-PASS FILTER

The frequency at which the inductive reactance equals the resistance in a low-pass or high-pass RL filter is called the cut-off frequency (f_C).

$$f_C = \frac{1}{2\pi\left({}^{L}/_{R}\right)}$$

As with the RC filter, the output voltage is 70.7% of its maximum value at f_C. All frequencies above the cut-off frequency (f_C) are passed by the high-pass filter and all those below are considered to be rejected, unlike low-pass filter.

$$X_L = 2\pi f L$$

$$Z = R + jX_L = \sqrt{R^2 + {X_L}^2} \qquad \theta = \tan^{-1}\left(\frac{X_L}{R}\right) \qquad V_O = \frac{V_{in}}{Z} \times X_L$$

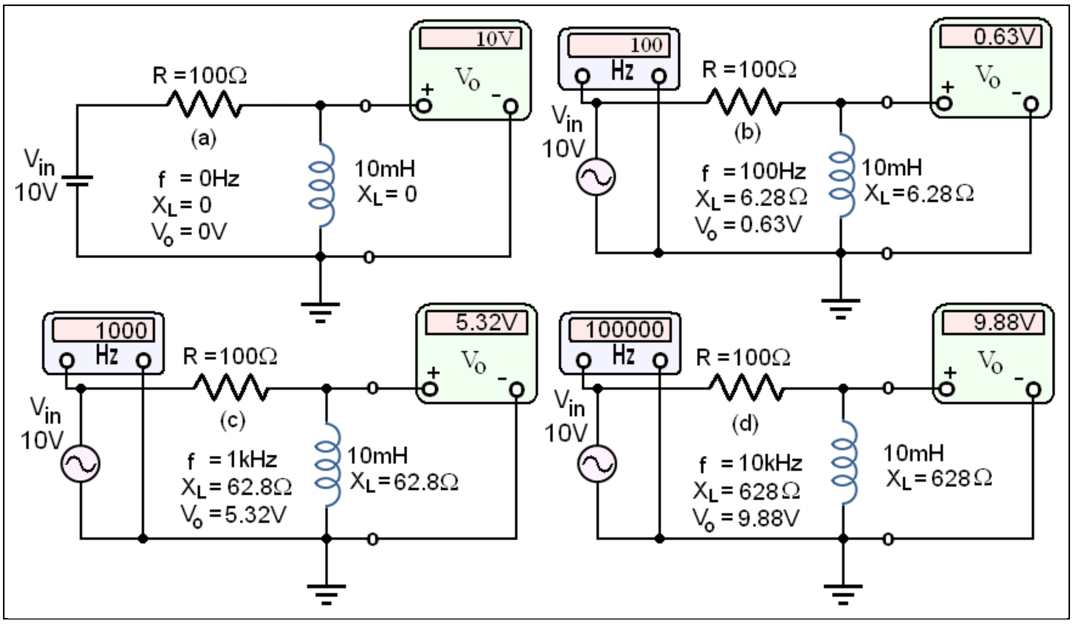


Fig. 2.2-12 RL High-Pass Filter Action (winding resistance neglected)

SINGLE-POLE BAND-PASS FILTER (BPF)

A band-pass filter passes all the frequencies within the bandwidth of the filter and rejects all others outside the bandwidth. As shown in Fig. 2.2-13, a low-pass and a high-pass filter can be cascaded to form a band-pass filter.

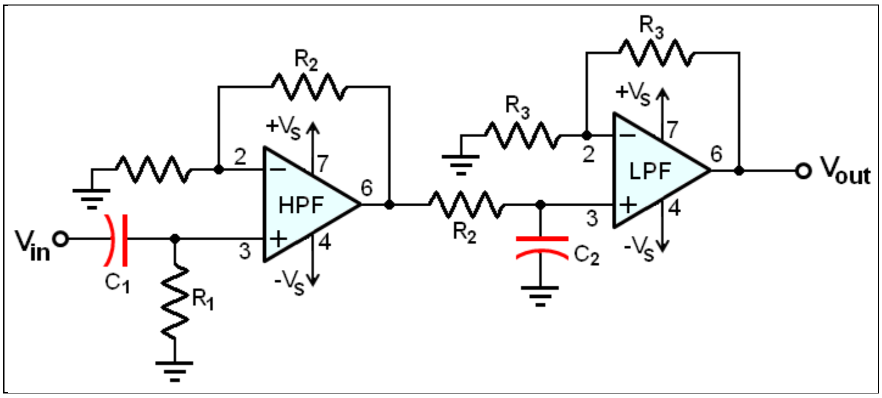


Fig. 2.2-13 Single-Pole Band-Pass Filter

CENTER FREQUENCY OF BAND-PASS FILTER

As shown in Fig. 2.2-14, the Center frequency (f_C) of the band-pass filter is called the resonant frequency (f_r) at which the voltage gain is maximum and is given by the square root of the product of the upper and lower cutoff frequencies.

$$f_r = \sqrt{f_L \, f_H}$$

Also the Quality factor (Q) is: $Q = {}^{f_r}/_{BW}$

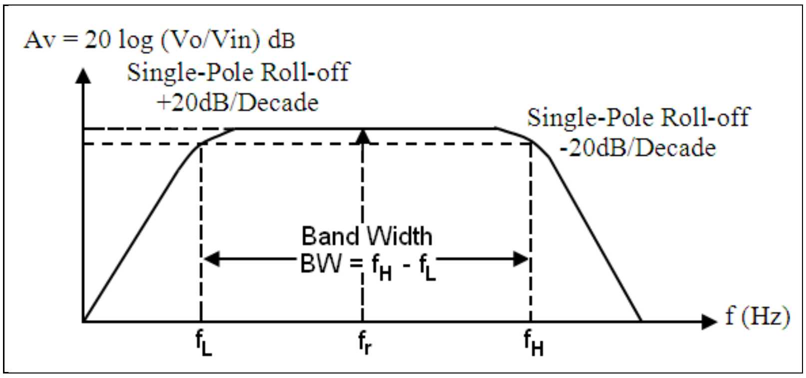


Fig. 2.2-14 Single-Pole Band-Pass Filter Response Curve

At the resonant frequency, the feedback signal is quite small compared to the output voltage V_O. To keep the inverting input at virtual ground, V_O must increase considerably at the critical frequency. That is, as the critical frequency approaches, the feedback signal decreases and as a result V_O increases.

RLC BAND-PASS FILTER

The two types of RLC band-pass filters are:

- Series resonant RLC band-pass filter
- Parallel resonant RLC band-pass filter

SERIES RESONANT RLC BAND-PASS FILTER

A basic series resonant band-pass filter is shown in Fig. 2.2-15. The series LC portion is placed between the input and the output and the output is taken across the resistor. This filter allows a band of frequencies to pass through below and above the resonant value from input to output without a significant reduction in amplitude. Signals with frequencies lying outside this specified band are reduced in amplitude at 20dB/Decade or 6 dB/Octave and are rejected by the filter.

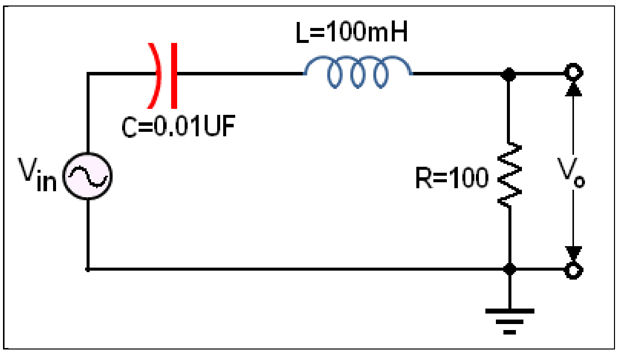


Fig. 2.2-15 Series Resonant RLC Band-Pass Filter

The filtering action is the result of the impedance characteristic of the filter. The impedance is minimum at resonance, when the capacitive reactance of the capacitor (C) is equal to the inductive reactance of the inductor (L).

$X_C = XL$ $X_C = 1/2\pi fC$ $X_L = 2\pi fL$

The impedance is increasingly higher below and above the resonant frequency. At very low frequencies, the impedance is very high and tends to block the current. As the frequency increases towards the resonance, the impedance drops, allowing more current to flow and thus more voltage across the output resistor.

At the resonant frequency, the impedance is very low and equal to the winding resistance of the coil. At this point a maximum current is flowing and the resulting output voltage is maximum. As the frequency goes above resonance, the impedance again increases, causing the current and the resulting output voltage to drop to 70.7% of the maximum current at resonance. The bandwidth of RLC band-pass filter is the same as shown in Fig. 2-15 for the single-pole band-pass active filter. The resonant frequency of RLC band-pass filter is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

The Quality factor (Q) of RLC band-pass filter at resonance is given by:

$$Q = {(X_L \text{ or } X_C)}/{R}$$

EXAMPLE 2.2-3

A certain RLC series resonant band-pass filter has a maximum current of 100mA at the resonant frequency. What is the value of the current at the cut-off frequencies?

SOLUTION

Current at the cut-off frequencies is 70.7% of maximum:

$$\mathrm{I\,f_H = I\,f_L = \ 0.707\,I_{max} = 0.707 \times (100mA)}$$

EXAMPLE 2.2-4

Given Fig. 2.2-15 for RLC series resonant band-pass filter: C = 0.005μF, L = 10mH, R_L = 10Ω, and R = 90Ω. Determine: $f_r = \frac{1}{2\pi\sqrt{LC}}$

a) Resonant frequency, f_r b) X_L or X_C c) Q d) BW

SOLUTION

a) $R_T = R + R_W$ = 90Ω + 10Ω = 100Ω

Resonant frequency,

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(10 \times 10^{-3})(0.005 \times 10^{-6})}} = 22.5 \text{ kHz}$$

b) X_L or X_C = 2πfL or 1/2πfC

= 2π(22.5kHz) (10×10^{-3}) or 1/2π(22.5kHz) (0.005×10^{-6}) ≈ 1414Ω

c) Q = XL/R = 1414/100 = 14.14

d) BW= fr/Q = (22.5kHz)/14.14 ≈ 1.6 kHz

RLC PARALLEL RESONANT BAND-PASS FILTER

A basic parallel resonant RLC band-pass filter is shown in Fig. 2.2-16. The output is taken across the parallel tank circuit in place of the resistor in this application.

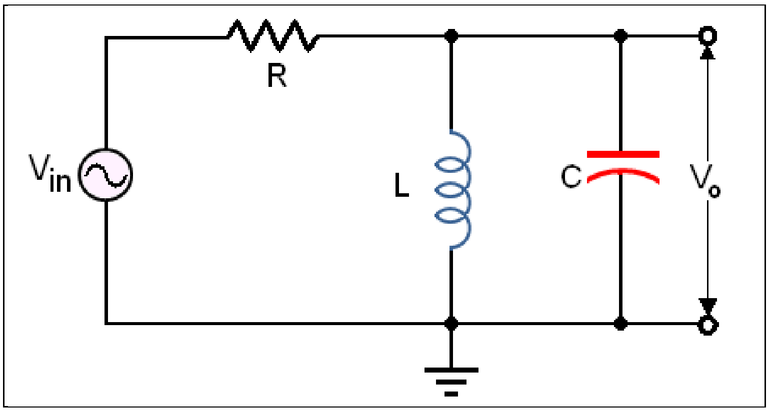


Fig. 2.2-16 Parallel Resonant RLC Band-Pass Filter

At very low frequencies, the impedance of the tank circuit is very low, and therefore only a small amount of voltage is dropped across it.

As the frequency increases, the impedance of the tank circuit increases and as a result, the output voltage increases. When the frequency reaches its resonant value, the impedance is at its maximum and so is the output voltage. As the frequency goes above resonance, the impedance begins to decrease, causing the output voltage to decrease. The bandwidth and cut-off frequencies for a parallel resonant band-pass filter are defined in the same way as for the series resonant circuit, and the formulas given. RLC band-pass response curves showing both V_O and I_T versus frequency are given in Fig. 2.2-17(a) & (b), respectively.

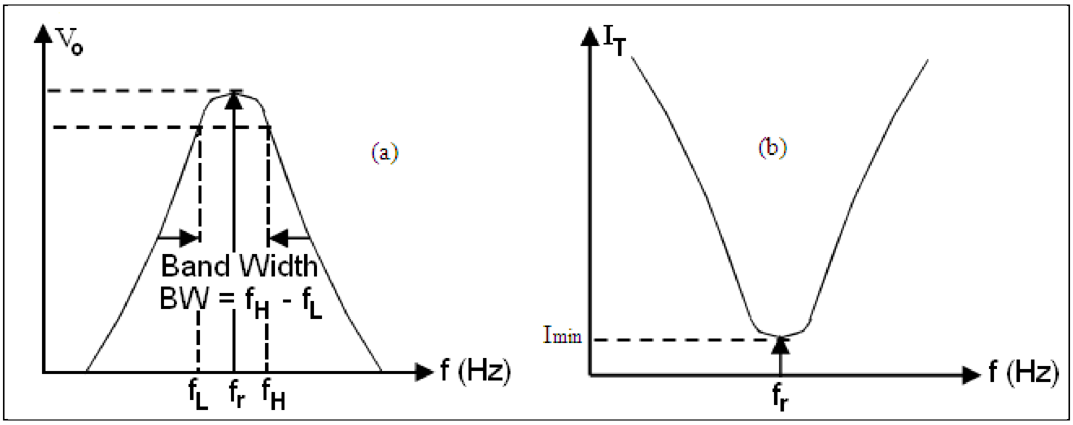


Fig. 2.2-17 RLC Band-Pass Response Characteristics

BAND-STOP (BAND REJECT OR NOTCH) FILTER

As shown in Fig. 2.2-18, a Notch filter passes all frequencies outside the bandwidth where the amplifier gain is maximum and rejects all the frequencies within the bandwidth of the filter where the amplifier gain is minimum between the upper and lower cutoff points.

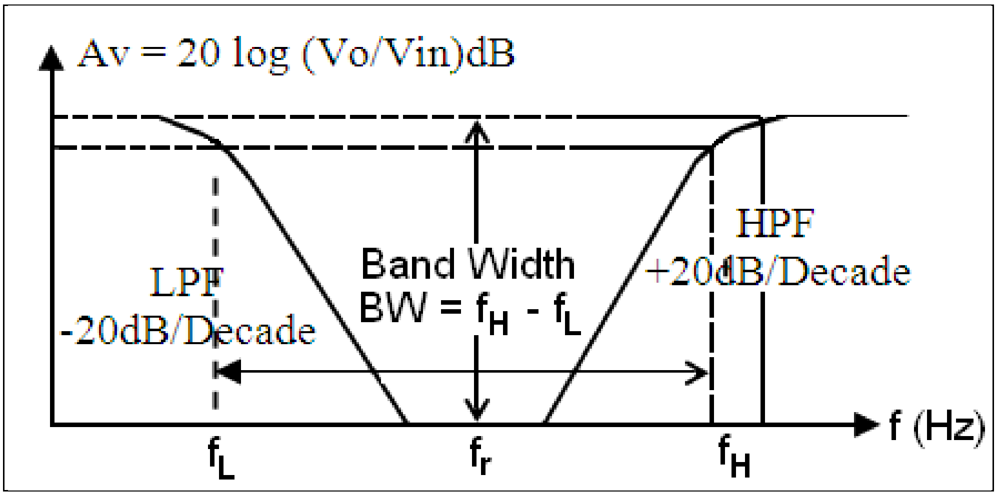


Fig. 2.2-18 Band-Stop (Band Reject or Notch) Filter Frequency Response

Fig. 2.2-19 shows a Single-Pole Notch filter where the LPF and HPF are cascaded (paralleled) through a single op-amp. At low frequencies below the lower cutoff (f_L), the capacitors C_{1L} and C_{1H} exhibits high impedance to the input signal at the inverting input terminal (-). The same signal is still applied to the non-inverting terminal and produces non-inverting output. At higher frequencies above the lower cutoff (f_L) but below the upper cutoff (f_L) the capacitors C_{1L} and C_{1H} exhibits low impedance to the input signal at the inverting input terminal (-) and act as being partially shorted.

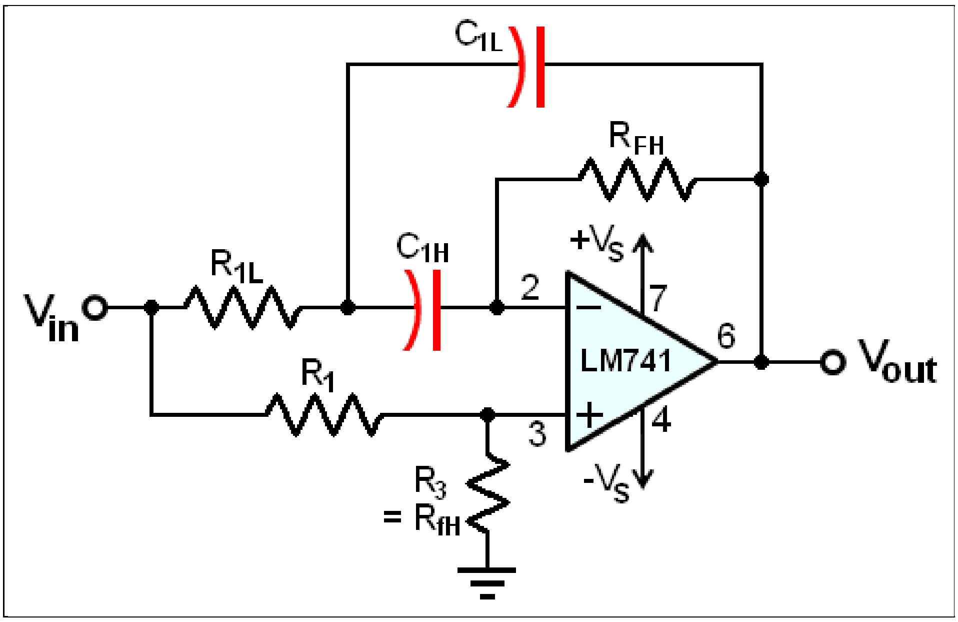


Fig. 2.2-19 Single-Pole Band-Stop (Band Reject or Notch) Filter

The same amplitude signal, when being applied to the non-inverting terminal acts as Common Mode input signal, the op-amp rejects all frequencies within the two cutoff points f_L and f_H, resulting in minimum output. When capacitors C_{1L} and C_{1H} are partially shorted, the op-amp will amplify the difference between the two inputs within the bandwidth of the filter. At resonant frequency (f_r), the output of the op-amp is minimum, meaning notched or cut down.

The resonant frequency (f_r) is given by:

$$f_r = \frac{1}{2\pi\sqrt{C_{1L}\, C_{2H}\, R_1\, R_f}}$$

SERIES RESONANT RLC BAND-STOP (BAND REJECT) FILTER

A basic series resonant RLC band-stop filter is shown in Fig. 2.2-21. The output voltage is taken across the series LC portion of the circuit. This filter is still a series RLC circuit, just like the band-pass filter. The difference is that in this case, the output voltage is taken across the combination of L and C rather than across R.

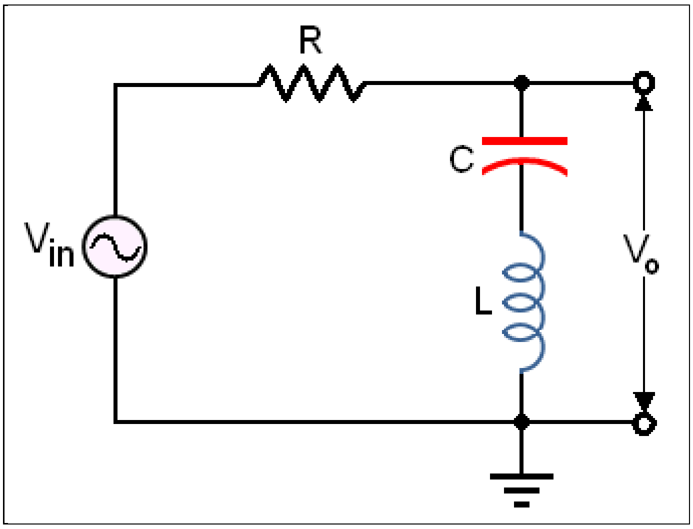


Fig. 2.2-20 Series Resonant RLC Band-Stop Filter

This filter rejects signals with frequencies between the upper and lower cut-off frequencies and passes those signals with frequencies below and above the cut-off values, as shown in the response curve of Fig. 2.2-18. The range of frequencies

between the lower and upper cut-off points is called the Stop-Band. This type of filter is also referred to as Band-Reject filter or Notch filter.

At very low frequencies, the LC combination appears as a near open due to the high X_C, thus allowing most of the input voltage to pass through to the output. As the frequency increases, the impedance of the LC combination decreases until, at resonance, it is zero. Thus, the input signal is ideally shorted to ground and there is very little output voltage. As the frequency goes above its resonant value, the LC impedance also increases allowing an increasing amount of voltage to be dropped across it.

EXAMPLE 2.2-5

Given Fig. 2-19 for series resonant RLC band-stop filter: C = 0.01μF, L = 100mH, R_L = 2Ω, and R = 50Ω. Determine: $f_r = \frac{1}{2\pi\sqrt{LC}}$

a) Resonant frequency, f_r b) X_L or X_C c) Q d) BW

SOLUTION

a) $R_T = R + R_W = 50\Omega + 2\Omega = 52\Omega$

Resonant frequency, $f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(100\times10^{-3})(0.01\times10^{-6})}} = 5\text{ kHz}$

b) X_L or $X_C = 2\pi fL$ or $1/2\pi fC$

$= 2\pi(5\text{kHz})\,(100\times10^{-3})$ or $1/2\pi(5\text{kHz})\,(0.01\times10^{-6}) \approx 3142\Omega$

c) $Q = X_L/R_T = 3142/52 = 60.42$

d) $BW = f_r/Q = (5\text{kHz})/60.42 \approx 82.75\text{Hz}$

SUMMARY

- The filters are classified as Active Filters and Passive Filters.
- Active Filters are tuned differential operational amplifier (op-amp) circuits in conjunction with resistors and capacitors.
- Passive Filters consist of inductors, capacitors, and resistors.
- Passive Filters are very bulky, expensive, and not very stable.
- The four basic types of Filters are:
  1. Low-Pass Filter
  2. High-Pass Filter
  3. Band-Pass Filter
  4. Band-Stop (Notch) Filter

- The Figure of Merit or Quality factor (Q) of a filter is the ratio of the resonant frequency (f_r) to the Bandwidth (BW) of the filter and is given by: $Q = f_r/BW$
- $Q > 10$ is called narrow bandwidth filter but with $Q < 10$ is wide bandwidth filter.
- The voltage gain of an active filter is determined by the ratio of the feedback impedance (Z_2) to the input impedance (Z_1).

$$A_V = \frac{V_O}{V_{in}} = \frac{Z_2}{Z_1} = \frac{R_2 + jX_2}{R_1 + jX_1}$$

- When the frequency is increased ten times above the higher cutoff, the gain drops by 20dB/Decade or 6dB/Octave in a LPF.
- The cut-off frequency (f_C) of a Single-Pole LPF or HPF is given by: $$f_C = \frac{1}{2\pi CR}$$
- At the cut-off frequency, the output voltage of a filter is equal to approximately 70% of the input voltage where the gain drops by 3dB:

$$V_O = \sqrt{2}\left(\frac{V_{p-p}}{2}\right) = 0.707\, V_{p-p}$$

- The resonant frequency (f_r) of a Single-Pole BPF at which the voltage gain is maximum is given by the square root of the product of the upper and lower cutoff frequencies.

$$f_r = \sqrt{f_L + f_H}$$

GLOSSARY

OP-AMP:	Operational Amplifier.
BW:	Band Width.
ROLL-OFF:	3dB slope of frequency response curve of a filter.
Q:	Figure of Merit or Quality factor of a filter, as the ratio of resonant frequency (fr) to Bandwidth (BW).
LPF:	Low-Pass Filter.
HPF:	High-Pass Filter.
BPF:	Band-Pass Filter.
BSF:	Band-Stop (Notch) Filter.

REVIEW EXERCISE

1. A tuned amplifier with a center frequency (f_C) of 1200 kHz has a bandwidth (BW) of 20kHz. The Quality factor (Q) of circuit is ______.

   a) 30 b) 60 c) 40 d) 50

2. The Quality factor (Q) of a tuned amplifier circuit is 25. If the center frequency (f_C) of the circuit is 1400 kHz, the filter bandwidth (BW) is ____ kHz.

   a) 25 b) 700 c) 40 d) 56

3. A tuned active amplifier has measured cutoff frequencies of 980kHz and 1080kHz. The resonant frequency (f_r) of the filter is approximately _____ kHz.

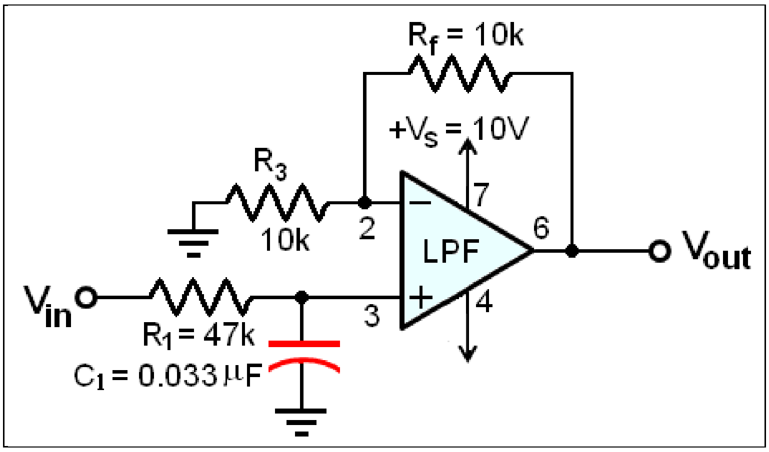
   a) 1030 b) 980 c) 1080 d) 100

4. A tuned active amplifier has measured cutoff frequencies of 980 kHz and 1080 kHz. The bandwidth (BW) of the filter is _____ kHz.

   a) 1030 b) 980 c) 1080 d) 100

5. For the following filter circuit, the gain is ______dB.

   a) 1 b) 1.5 c) 2 d) 0.2



6. For the last Single-Pole Low-Pass Non-Inverting Filter, the cutoff frequency (f_{C2}) is approximately ______Hz. $f_{C2} = \frac{1}{2\pi\, R\, C}$

   a) 104 b) 102 c) 103 d) 101

7. when the frequency is increased ten times above the higher cutoff, the gain drops by 20dB/Decade or 6dB/Octave in a HPF. True or False

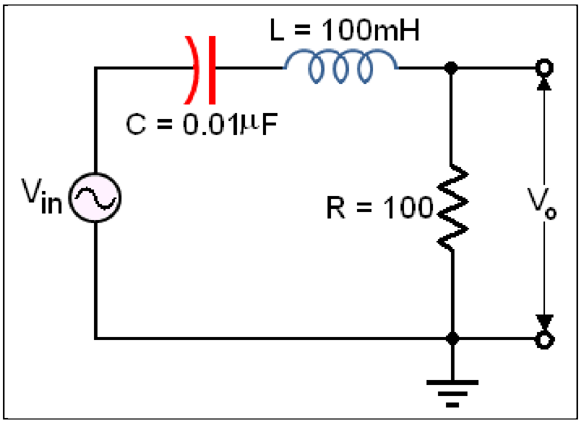
8. The capacitive reactance of a capacitor ________ as the frequency is increased at the input of a filter.

9. A certain RLC series resonant band-pass filter has a maximum current of 1A at the resonant frequency. The value of the current at the cut-off frequencies is __.

   a) 1A b) 1.707A c) 0.707A d) 0A

10. Given RLC series resonant band-pass filter: C = 0.01μF, L = 100mH, R_L = 10Ω, and R = 100Ω. The Resonant frequency, f_r is ____kHz: $f_r = \frac{1}{2\pi\sqrt{LC}}$

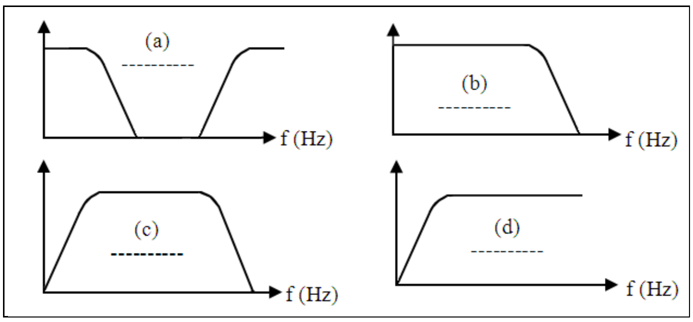
   a) 5 b) 1 c) 100 d) 10

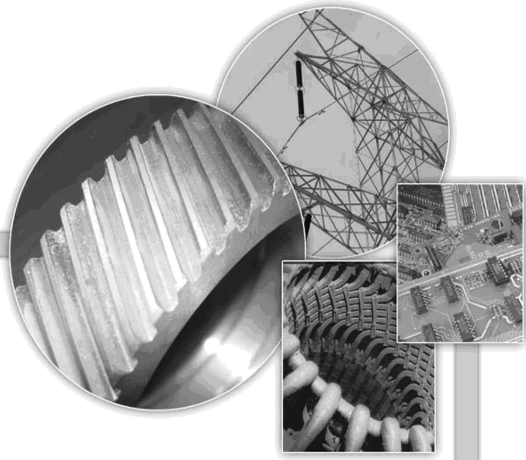


11. The other name of a Band-Stop Filter (BSF) is ___________ filter.

   a) Notch b) Band-Reject c) Band-Pass d) a or b

12. Indicate the types of filters from the frequency response curves.





LESSON 2.3

CARRIER EQUIPMENT

LESSON 2.3
CARRIER EQUIPMENT

OVERVIEW

This lesson discusses the types of communication channels. It scopes out the applications of carrier relaying and pilot protection systems. The directional comparison blocking and unblocking systems are included in this lesson.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

1. State different types of communication channels.
2. Describe PLC parts.
3. Describe general carrier relaying concepts.
4. Classify pilot protect systems.
5. Describe directional comparison blocking system.
6. Describe directional comparison unblocking system.
7. Describe permissive overreach transferred trip.
8. Describe phase comparison carrier current protection.

CARRIER CURRENT RELAYING

Carrier current relaying is an intercommunication system between two or more terminals of a transmission line panel, which relaying information is transferred from terminal to terminal. The location of a fault is determined by comparing simultaneous observations from each terminal via these communications.

POWER LINE CARRIER

In the application of protective relaying to power system, the relay technician must know the necessity of providing a channel of communication between two or more system locations for the transmission of relay "intelligence" from one point to another. His primary concern is to provide adequate relay protection to detect, locate and isolate system faults promptly and at the same time, maintain adequate availability of power to consumers.

The most effective relaying schemes require that information, which is available at two or more locations be compared. Such comparison permits simultaneous tripping of all terminals of a line section. The communication channel provides the necessary link for this comparison of relay intelligence. When a fault occurs, each location supplies the information for coordination in determining whether the section is to be tripped or left intact. The selection of the best communication channel for protective relaying is governed by a number of considerations. The distance between stations, nature of terrain, functions required, all affect the selection of the most desirable link. At the present time, the following methods are in common use:

MICROWAVE

In this system, the signal is carried at a much higher frequency that is between 2,000 and 12,000 Megahertz. This super high frequency signal (SHF) is transmitted by radio from terminal to terminal (Fig. 2.3-1). At each terminal, a dish antenna is installed and the transmission must be by line of sight.

Fig. 2.3-1 Using Microwave Communication

The microwave communication system will be used for many different functions such as voice communication, data communication, information transfer, loading instructions, switching instructions and protective relaying, all operating at different specific frequencies. The microwave system has the advantage that it can accommodate a huge number of channels. This is accomplished by the technique of multiplexing; you will study this later on.

FIBER OPTICS

In this arrangement, the signal is transmitted by light waves travelling through an optical fiber. The fiber is made of non-conducting material, so it cannot provide a path for electrical signals. At the transmitting end the electrical signal, perhaps a tripping signal from a relay, is converted into a beam of light. The signal is able to travel around bends providing they are not too acute. At the receiving end, the light beam is converted back into an electrical signal to initiate action, say tripping of a breaker.

AUDIO TONE EQUIPMENT

Using transmitters and receivers operating in the 600 to 3 kHz frequency band, utilizing a privately owned or leased pilot wire channel, or as modulation on microwave channels.

PILOT WIRE EQUIPMENT

Using 60 Hz power either frequency or d-c signals.
Pilot wire relaying is used where the distance between each end of the line is quite short, say up to 10 miles.

POWER LINE CARRIER CHANNEL

In this system, the signal is transmitted at a specific tuned frequency selected within the range 30 to 500 kilohertz. This high frequency signal is super-imposed upon one of the power line conductors, usually the center conductor to reduce the effect of mutual inductance. The power conductor provides the metallic path for the signal. Fig. 2.3-2 shows the arrangement.

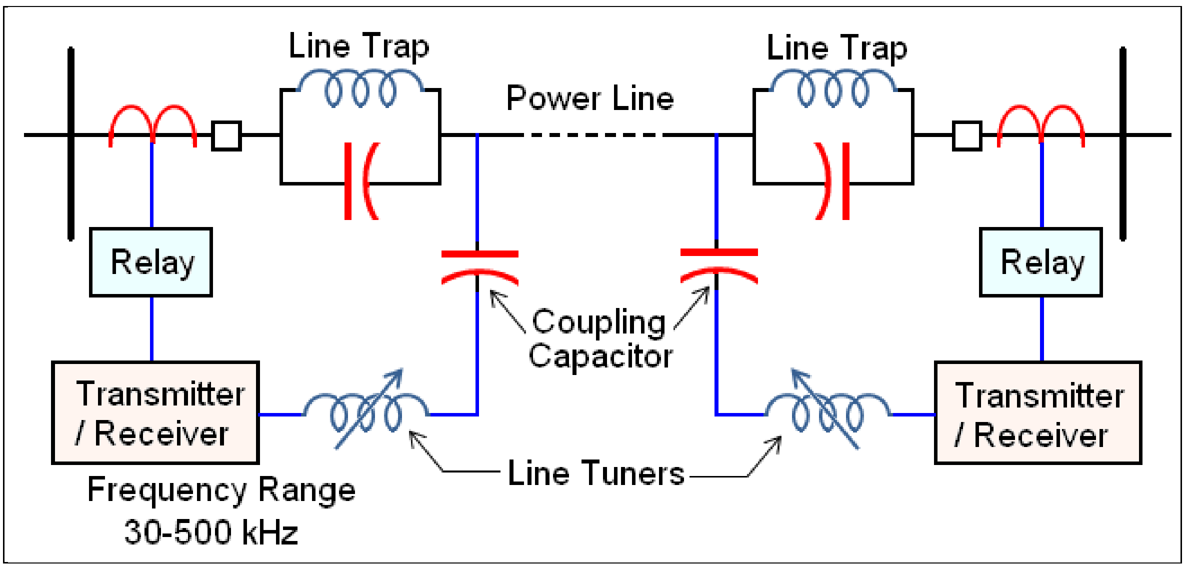


Fig. 2.3-2 Power Line Carrier System

The high frequency signal is confined to the power line by the line traps. The line trap consists of a capacitor and reactor in parallel to form a resonant circuit. This is tuned to provide zero impedance to 60 hertz current but to provide very high impedance (almost open circuit) to the 250 kHz signal.

It effectively blocks the escape of the high frequency signal. As the line traps are placed in series with the power line, the equipment, that is the reactors and capacitors, must be very robust and capable of passing high fault currents, say, 60,000 amps.

In order to inject the high frequency signal into the high voltage power line, a coupling capacitor is used. This is a large, high voltage capacitor, which is capable of withstanding the power line voltage under both fault and switching surge conditions. This effectively provides the insulation of the high voltage line at say 230 KV from the low voltage transmitting equipment, say 120V.

The value of the capacitor is selected so as to provide high impedance to the 60-hertz line current and low impedance to the high frequency signal.

Inductive reactance $X_L = 2\pi fL$ f - frequency

Capacitive reactance $X_C = \frac{1}{2\pi f C}$ L - inductance

C - capacitance

The high frequency impedance is reduced by adding a reactor in series. By tuning the reactor, we can select the coupling circuit to pass specific carrier frequencies as desired. This circuit is called the line tuner. At the receiving end of the line, a similar coupling capacitor and tuner are installed. Provided the line tuner is adjusted to the same frequency, the transmitted signal flowing along the line will now pass into the receiver for appropriate action. Both a transmitter and a receiver are installed at each end of the line.

In the on/off system, the receiver is normally "on" waiting to receive a signal on its tuned frequency. When the protection relay (say a distance relay or an instantaneous relay) detects a fault, it switches on the transmitter, which then sends the signal along the line at the pre-set frequency. The receiver picks up the signal and initiates appropriate action by energizing the control circuit.

This method of transmittal is known as on-off because in normal operation, the receiver is "on" but the transmitter is "off" and is turned on only when action is required. Another method more commonly used today initiates a *change* in signal frequency to produce action at the far end. In this arrangement, under normal operating conditions, both transmitter and receiver are switched on all the time and a guard signal is flowing continuously at a specific frequency. When the relay detects a fault it will switch or key the transmitter to different frequency. This is known as shift "keying" the frequency. The receiver at the far end responds to the change in frequency, and initiates appropriate action.

This system is called FSK, Frequency Shift Keying. It has the advantage that if the communication equipment fails at any time, loss of the continuous "guard" signal will be noticed and appropriate action taken. The protective relays receive their intelligence from the current and potential transformers in the protected line. Under fault conditions the relays operate, initiating a signal in the carrier transmitter, which passes through the line tuner and coupling capacitor to the transmission line and hence over the line to the remote terminal. comparison of this signal with the relay status at the remote terminal determines whether the line section is to be tripped out or kept intact (on external faults, for example). The line trap prevents the carrier signal from being grounded by an external fault.

CARRIER TRANSMITTER AND RECEIVER

(I) TRANSMITTER UNIT

Fig. 2.3-3 shows the general arrangement of power line carrier protection scheme.

Frequencies between 50 to 500 kHz are employed in different frequency bands. Each band has certain band width (say 150-300 kHz, 90-115 kHz). Carrier frequencies are generated in oscillator. The oscillator can be tuned to a particular frequency selected for the application. On the other hand, it can be a crystal oscillator with which the operation for a particular bandwidth can be achieved by selecting on appropriate crystal. The output voltage of the oscillator is held constant by voltage stabilizers.

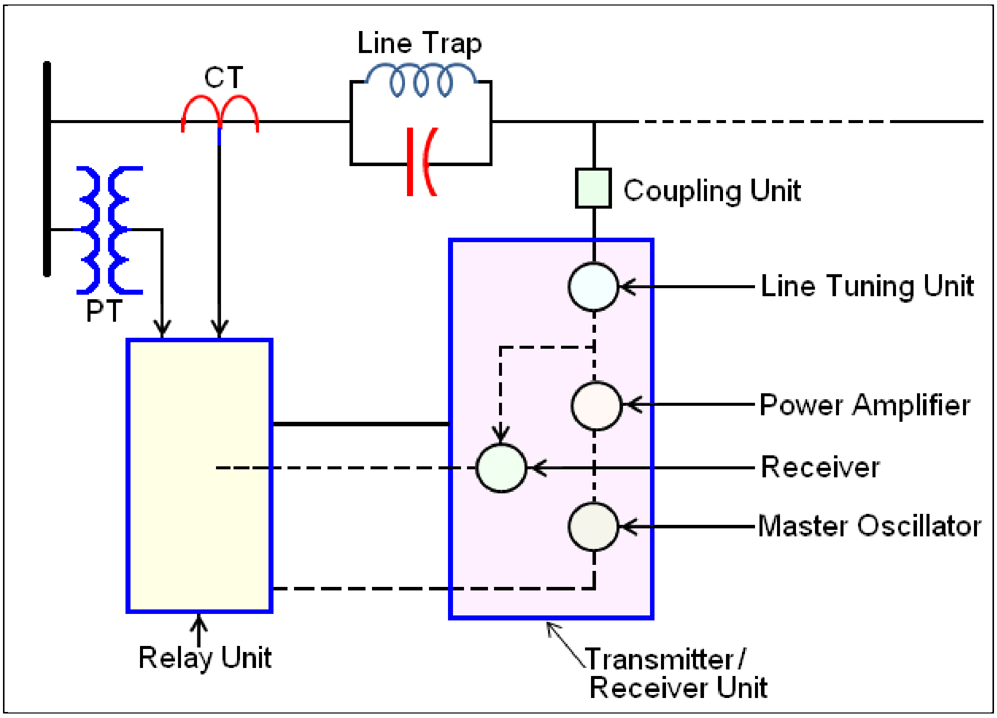


Fig. 2.3-3 Schematic Diagram of Carrier Current Units

The output of the amplifier is fed into the amplifier (to increase the signals to be transmitted) to overcome the losses in the transmission path between the transmitter and the receiver at remote end of the line. Signal attenuation comprises.

- Losses in coupling equipment, which are constant in the given frequency, range.
- Line losses, which vary with length of line, frequency weather conditions, tee of connections of the line, the size, and type of line. The H.F. losses of underground line are higher than overhead line.

  The losses in overhead line are affected by weather. In fair weather, the attenuation is about 0.1 dB/km at 80 kHz rising to 0.2 dB/km at 380 kHz. The output of amplifier is of the order of 20 W for a 250 km line. The amplifier should be designed for maximum power over a selected bandwidth.

  The control of transmitter can be achieved by different methods depending upon the type of protection desired.
- Amplifier constantly energized, transmission is initiated by energizing the oscillator. In this method, the oscillator stability and response time is a constraint.

(II) RECEIVING UNIT

The high frequency signals arriving from remote end are received by Receiver. The receiving unit comprises (Figure 4):

- An attenuator, which reduces the signals to a safer value.
- Band pass filter, which restricts the acceptance of unwanted signals (signals from adjacent sections, spurious signals).
- Matching transformer or matching element to match the impedances of line and receiving unit.

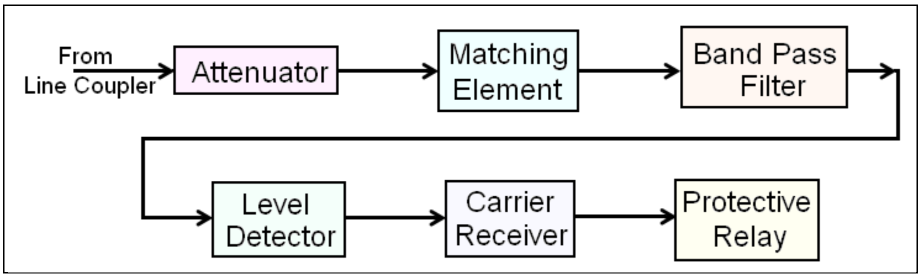


Fig. 2.3-4 Block Diagram of Receiving Unit

The spurious signals are caused by short-circuits, radio interference. To avoid the mal-operation due to noise, a setting above 2 milli-watts is recommended to be given to the receiver. This setting is above the noise level. To avoid operation due to spurious signals, the carrier signals should have higher power level (20W) and receiver should be set at a higher level (5 milli-watts). Before feeding the signals to amplifier detector, the signals should be attenuated to avoid overloading.

GENERAL CARRIER RELAYING CONCEPTS

All carrier relaying systems (or microwave, tone, or pilot wire) are basically a "differential" relaying concept where currents, voltages, or power flow are compared at two points to determine whether a fault or other undesirable condition is internal or external to the protected zone. If internal, the objective is to trip all breakers associated with the faulted section simultaneously at high speed. If the fault is external, the normal objective is to prevent the associated breakers from tripping.

There are two basic carrier relaying schemes, directional comparison and phase comparison.

CARRIER-CURRENT RELAYING

Carrier-current relaying is an intercommunication system between two or more terminals of a transmission line over which relaying information is transferred from terminal to terminal. The location of a fault is determined by comparing simultaneous observations from each terminal via these communications.

The carrier transmitter sends out a high-frequency current (30 to 500 kilo-cycles), which is carried over one of the power conductors to convey relaying information.

The carrier receiver used is selective to the carrier frequency, and will respond to its local transmitter as well as the transmitter at the remote terminal of the protected section. The carrier receiver converts the received carrier current into a dc current to perform the desired relay functions.

FAULT CURRENT COMPARISON

When a fault occurs, the directional relays determine whether the fault is internal (in the protected section) or external (outside the protected section). When an internal fault occurs, the line is quickly cleared by tripping the circuit breakers at each terminal. When the fault is external, the breakers do not trip immediately, but allow time for the breakers of the faulted section to clear the fault.

Three adjacent transmission line sections are shown in Fig. 2.3-5 with circuit breakers at A, B, C, D, E and F; and faults at locations X, Y, and Z. The section between breakers C and D, protected by carrier-current relaying, is under consideration.

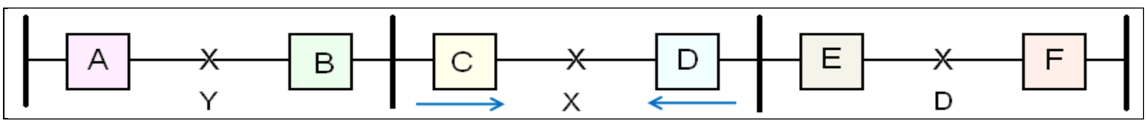


Fig. 2.3-5 Typical Transmission Line Sections

The directional relays at breaker C operate only for faults to the right of breaker C but the relays at breaker D operate only for faults to the left of breaker D. This means that the only faults that can operate both the directional relays at C & D are those faults that occur between C and D (internal faults). Faults, such as, Y or Z would operate the directional relays at only one terminal of section C-D at is, fault Y would operate only the directional relays at D, and fault Z would operate only the directional relays at C. In this manner, the scheme distinguishes between internal and external faults. It is a function of the carrier-current channel to indicate instantaneously to both terminals whether the directional relays at both terminals (C and D) have operated.

CARRIER-CURRENT TRANSMISSION

Transmission of a carrier-current signal is started by the operation of either the phase-to-phase or the phase-to-ground fault detector (carrier start) relay element. A signal transmitted from either terminal of a line section will prevent "block" instantaneous carrier-current controlled tripping of the terminal breakers. This does not prevent normal tripping of the breakers through the protective relays. For an external fault, the carrier signal will be transmitted from one terminal, the terminal at which power flows from the internal section to the external section. For an internal fault, the carrier signal will be stopped at both terminals by the instantaneous operation of the directional relay elements. When the carrier signal is stopped, the line breakers are permitted to trip instantaneously instead of through a time delay element.

REMOTE TRIP - FREQUENCY SHIFT "FSK" SYSTEM

The local transmitters send a continuous signal called a guard or guard frequency to the remote terminals. Under fault conditions, this guard frequency is shifted. The remote receiver responds to this shift and sets up a circuit for tripping its breaker. A loss of guard frequency will sound an alarm but not trip the breaker. When the need for a remote trip is indicated, the transmitter shifts from its guard frequency to a trip frequency to cause the tripping of the breaker at the remote terminal.

This remote trip feature is used to provide protection on a transformer not equipped with a primary breaker.

REMOTE TRIP - TONE

Remote tripping is also accomplished by using the carrier-current signal and modulating it with audio tone signals. The modulation components are extracted from the carrier signal at the receiving end, and they are used to operate tripping relay on the protected line. Transmission of the modulated carrier signal occurs only during fault clearance. When tone trip is employed, no guard frequency is used.

CLASSIFICATION OF PILOT SYSTEM

Carrier pilot relaying can be classified according to channel usage or the fault detection principle used.

a) By Channel Use: In terms of channel used, all pilot systems either blocking systems or transfer-trip. In the blocking systems, the channel is used only to prevent one of remote terminals from tripping on external faults. A channel signal is not required for internal faults, that is, tripping occurs in the absence of a channel signal.

   In the transfer-trip systems, a channel signal must be transmitted and received before tripping occurs on internal faults. No channel signal is required for external faults.

b) By-Fault Detection Principle: In the directional comparison systems, fault detecting relays compare the direction of power flow at the two line terminals. Power flow into the line at both terminals indicates internal fault, and the line is tripped. If the power flow is into the line at one end and out of the line at the other end, the fault is considered to be external, and the line is not tripped.

The phase comparison systems generally use overcurrent fault detecting relays to compare, via the channel, the relative phase of the currents at the terminals. If the current at the terminals are relatively 180° out of phase, an external fault or through-load current is indicated, and the line is not tripped.

COMPARISON CARRIER RELAYING

The basic principles are to compare the direction of power flow at the two ends and continuously to compare the instantaneous phase relation of the currents_at the two ends.

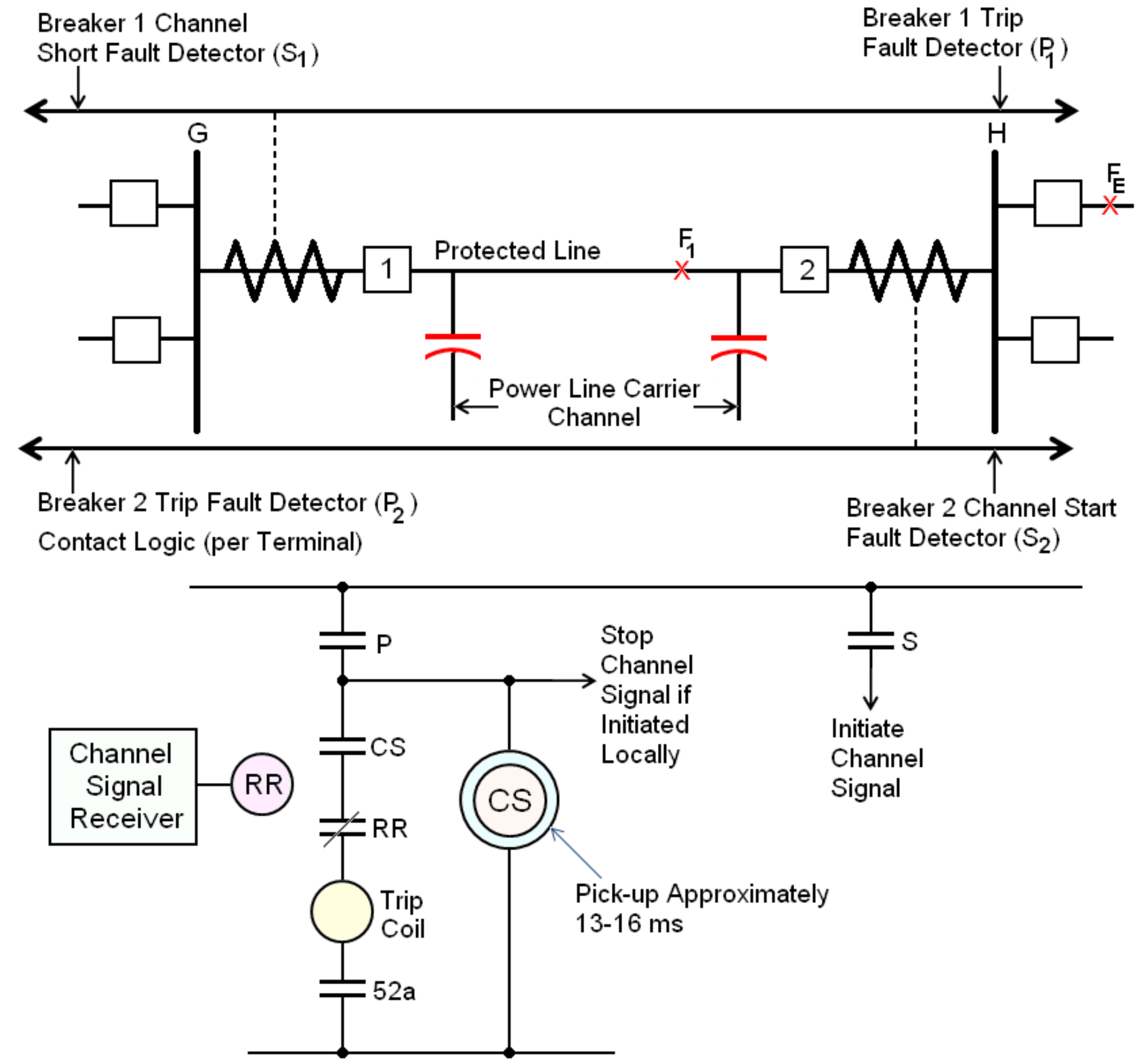
(a) DIRECTIONAL COMPARISON

In directional comparison pilot schemes, the direction of power flow is compared by means of the relative position of the contacts of directional relays at the two ends of the protected section. The directional comparison schemes normally use directional distance fault detectors for phase faults with directional overcurrent or directional distance fault detectors for ground faults. These relay schemes can be divided into four categories:

- i Directional comparison blocking system.
- ii Directional comparison unblocking system.
- iii Overreach transfer-trip systems.
- iv Permissive or non-permissive under reaching transfer-trip system.

I. DIRECTIONAL COMPARISON BLOCKING SYSTEMS

The basic elements for directional comparison are shown in Fig. 2.3-6. Operation of the directional comparison scheme is given in the table beside.



Type of Fault	Events at Station G	Events at Station H
External (F_E)	P_1 operates; S_1 does not see fault. Blocking signal received from station H. RR back contacts open with no trip.	S_2 operates to key transmitter. Blocking signal send to station G. P_2 does not see fault. And no trip.
Internal (F_1)	P_1 operates. S_1 may or may not operate, but P_1 operation prevents transmission of blocking signal, breaker 1 trips.	P_2 operates. S_2 may or may not operate, but P_2 operation prevents transmission of blocking signal, breaker 2 trips.

Fig. 2.3-6 Simplified Diagram of Directional Comparison blocking System

II. DIRECTIONAL COMPARISON UNBLOCKING SYSTEMS

Directional comparison unblocking systems transmit a continuous blocking signal, except during internal faults. That is, the S channel start-fault detectors are not required. The channel is generally a frequency-shift (FSK) power line carrier. A blocking (guard) frequency is transmitted continuously during normal conditions. For an internal fault, the FSK transmitter is shifted to the "unblock" (trip) frequency.

The frequency-shift channel is monitored continuously prevent tripping when a loss of channel occurs.

Fig. 2.3-7 shows elements for directional comparison unblocking systems. The phase and ground trip fault detectors at both stations must operate for all internal faults; that is, they must overreach the remote bus.

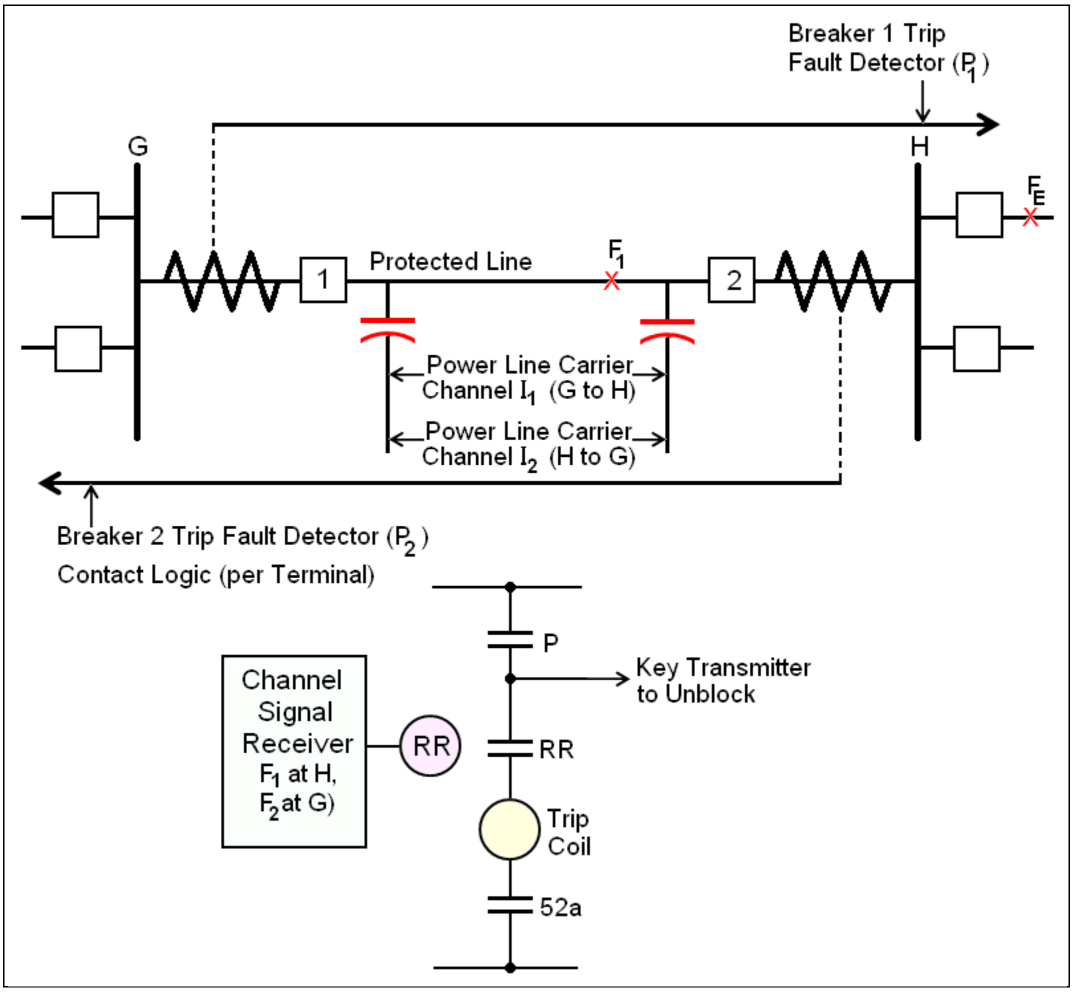


Fig. 2.3-7 Simplified Diagrams of Directional Comparison Unblocking System

Type of Fault	Events at Station G	Events at Station H
External (F_E)	P_1 operates; S_1 channel shifts to unblock. F_2 channel continues block. And no trip.	P_2 does not see fault. Loss of block and/ or receipt of unblock (F_1) operates RR. No trip.
Internal (F_1)	P_1 operates. F_1 channel to unblock. Loss of block and/ or and receipt of unblock (F_2) operates RR trip.	P_2 operates. F_2 channel shifts to unblock. Loss of block and/ or receipt of unblock (F_1) operates RR trip.

III. PERMISSIVE OVERREACH TRANSFERRED TRIP

Permissive overreach transferred trip, is a method of line relaying using some form of communication, such as tone trip or frequency shift, to provide directional comparison of currents at the line terminals. Two separate communication lines or carrier channels are used. Directional relays are used at each end for phase and ground fault protection. These relays are represented as "R" in Fig. 2.3-8.

A line fault external to protected section A-B may operate the relays at one terminal and send a trip signal to the opposite end, but no tripping will occur at either end because both the R and the T contacts must be closed to allow trip.

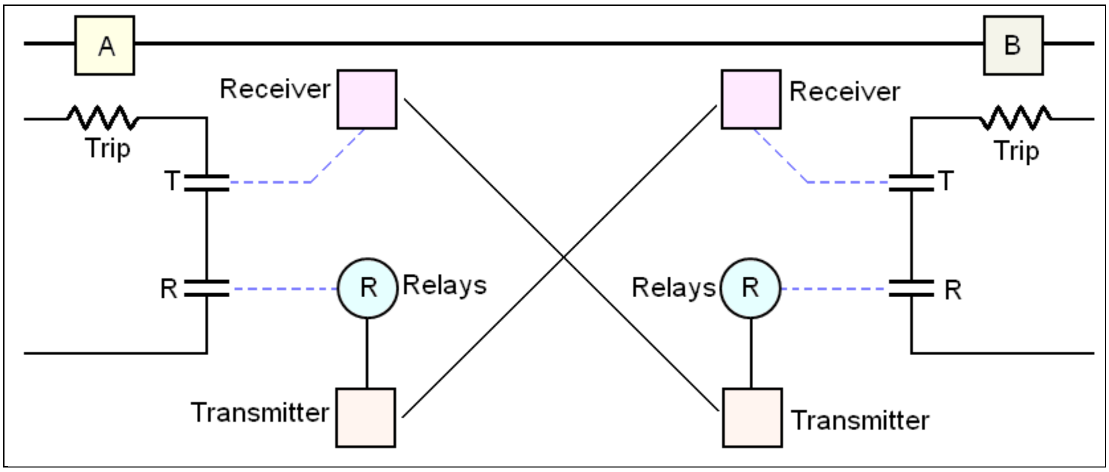


Fig. 2.3-8 Permissive Overreach Transferred Trip

A fault within line section A-B will cause relays at both ends of the line to operate, and both ends will send trip signals. Since both the R and the T contacts are closed at each end, both breakers will trip. High-speed directional protection can be achieved by this method. It is used as a back-up scheme for first-line relays.

IV. DIRECTIONAL COMPARISON OVERREACHING PERMISSIVE SCHEME

In this arrangement, the transmitters are switched on all of the time and a signal is transmitted continuously to the other end of the line. Actually, the two transmitters, and their associated receivers at the other end, are tuned to two different frequencies usually within an interval of about one kilohertz. This prevents a transmitter from inadvertently tripping its own breaker. Fig. 2.3-8 shows the arrangement.

The continuous "guard" signal is a blocking signal which prevents operation of the relays under normal operating (that is, no-fault) conditions. As the transmitters are continuously on there is no need for starting relays.

Consider a fault on bus G. The fault detector FDI that is a directional distance relay will not operate for this fault up stream. Therefore, the transmitter at station G continues to send its blocking signal to station H. However, the fault detector at bus H (FD2) does register the fault because one relay is set to overreach into the next section. It tries to trip breaker 2, but it cannot trip breaker 2 because of the blocking signal being received from terminal G.

Operation of the fault detector at bus H also keys the transmitter at station H to change its transmitting frequency, from the guard signal to the trip signal. This is usually achieved by lowering the frequency by about 200 hertz. At the same time signal, power is increased from one watt to ten watts. When this signal is received at station G the relay is released to operate. However, as we have just mentioned this relay FDI does not register the upstream fault and therefore will not trip. In effect the transmitted signal is applied as a permissive, which allows the relay to trip when the fault is within the protected zone.

(b) PHASE COMPARISON CARRIER CURRENT PROTECTION

Phase comparison method compares the phase relation between current entering and leaving in the protected zone. The magnitudes of currents are not compared. Phase comparison provides only main protection. Back up protection should be provided in addition. In one of the phase comparison methods signals are sent from each end of the line and received at the other end. The signals are related to the current flow in the main line, as they are derived from CT secondary current.

Referring to Fig. 2.3-9, for internal fault condition shown on right hand side, the transmitted signals and received signals are almost in phase. The comparator compares these signals. Due to absence of signals for alternate half cycles, the comparator gives output causing operation of trip relay.

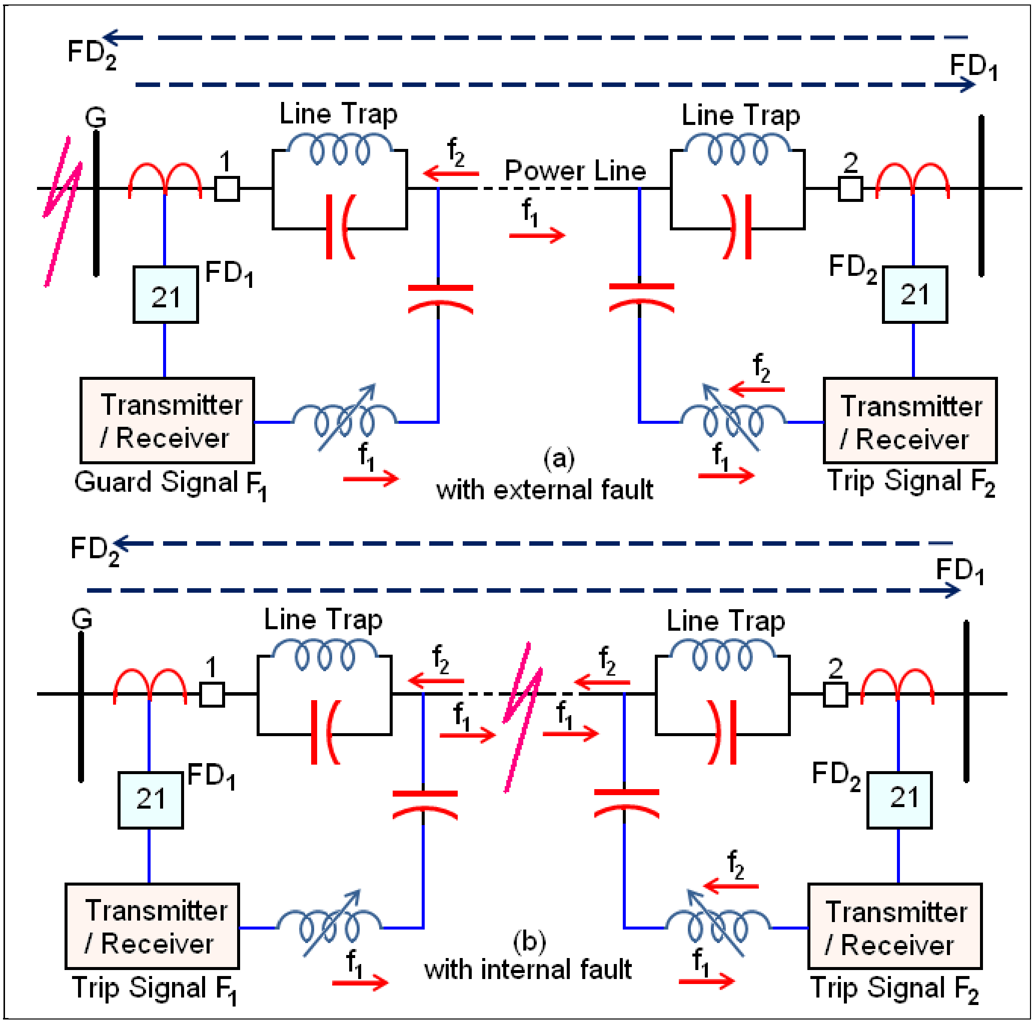


Fig. 2.3-9 Directional Comparison Overreaching Permissive Scheme

When there is no fault, the signal is sent for alternate 1/2 cycles from each end which result in continuous signal over the line half the cycle from one end, remaining half from the other. The same condition holds good for an external fault. During internal fault the current in one of the lines reverses in phase or differs in phase and remains below the fault detector setting, so that carrier is sent only for half the time. The relay is arranged to sense the absence of signal in the line. Depending upon the setting, the tripping occurs when the phase angle between the two signals reaches a certain value.

Carrier signals are transmitted to the line from both ends. For external faults the effect produced by the sum of these two signals is similar to that obtained when a continuous high frequency carrier is available on the line, and the protection is designed to remain stable under the condition. The sum of these two signals on all internal faults produces an effect similar to the periodic suppression of such a continuous carrier, the duration of each suppression being proportional to the phase displacement between the primary current at both ends. The protection is designed to operate for phase-displacements greater than a normal angle of 30°. Thus for phase-displacements of less than 30° the protection will stabilize. This angle is referred to as the stabilizing angle of the protection.

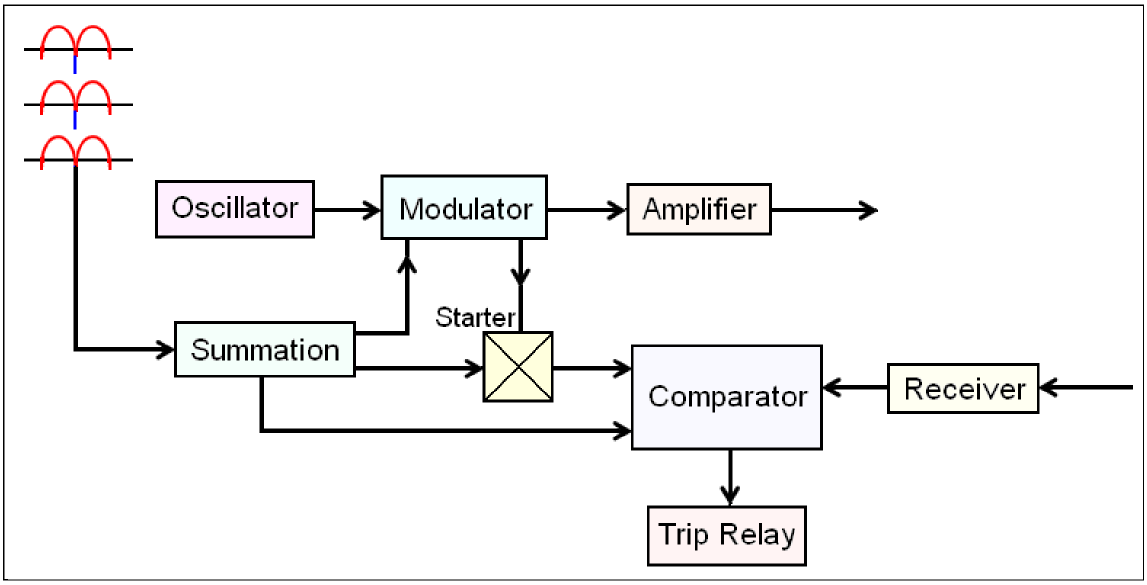


Fig. 2.3-10 Block Diagram of Phase Comparison Circuit

Fig. 2.3-11 illustrates the two extreme cases with symmetrical fault conditions. The external-fault condition is implied by the fact that the primary current at both ends is in phase and the internal fault condition by the fact that the two primary currents are 180° out of phase. As a first step to produce the required carrier-signals the secondary current at one end only (end B) is made 180° out of phase with the primary current by a reversal of the current-transformer connections. Thus for external faults the secondary currents at the two ends are 180° out of phase with each other as shown in Fig. 2.3-11.

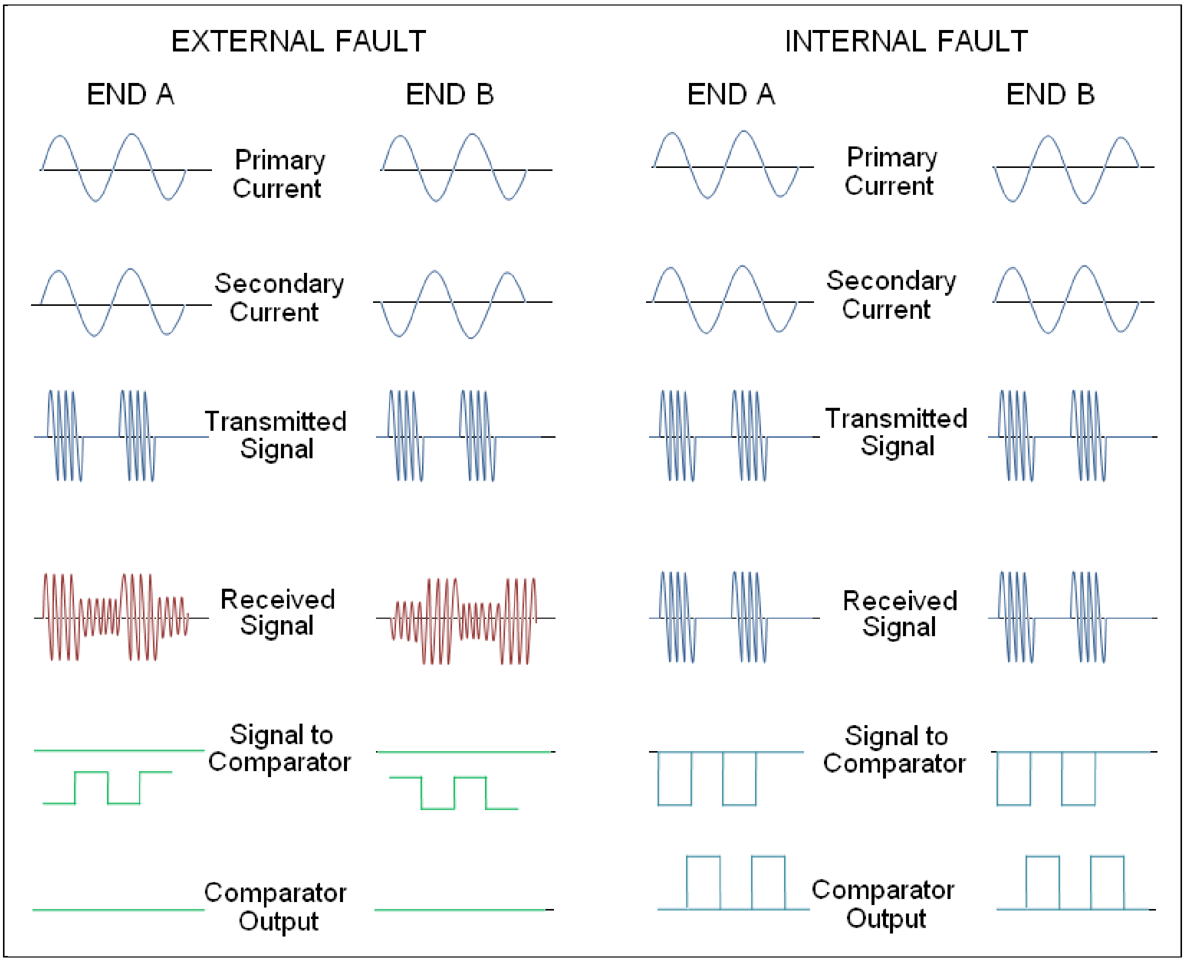


Fig. 2.3-11 Diagram Illustrating the Principle of Phase Comparison method

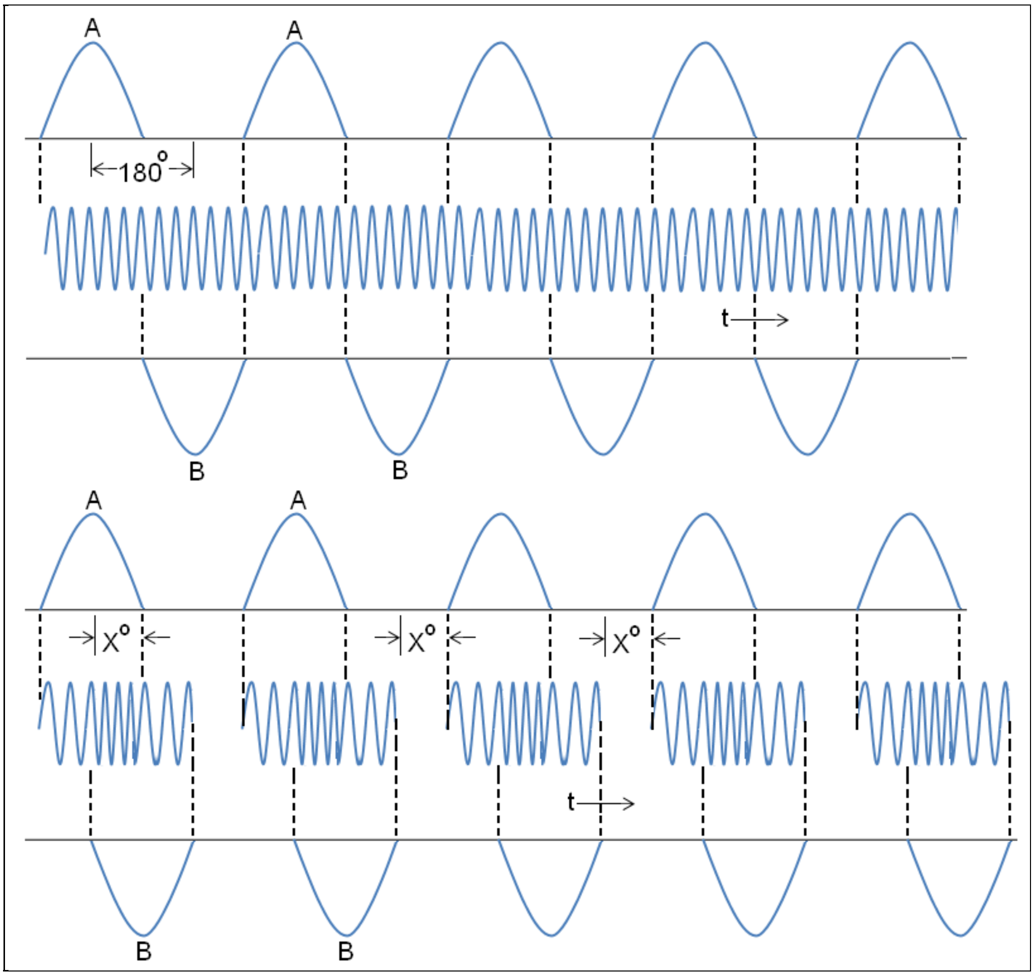


Fig. 2.3-12

APPLICATIONS OF CARRIER CURRENT RELAYING

Pilot channel such as carrier current over the power line provides simultaneous tripping of circuit-breakers at both the ends of the line in one to three cycles. Thereby high speed fault clearing is obtained, which improves the stability of the power system. Besides there are several other merits of carrier current relaying. These are:

1) Fast, simultaneous operating of circuit-breakers at both ends.
2) Auto-reclosing simultaneous reclosing signal is sent thereby simultaneous (1 to 3 cycles) reclosing of circuit-breaker is obtained.
3) Fast clearing prevents shocks to systems.
4) Tripping due to synchronizing power surges does not occur, yet during internal fault clearing is obtained.

5) For simultaneous faults, carries current protection provides easy discrimination.
6) Fast (2 cycle) and auto-reclosing circuit-breakers such as air blast circuit-breakers require faster relaying. Hence, the carrier current relaying is best suited for fast relaying in conjunction with modern fast circuit-breakers.
7) Other uses of carrier equipment. The carrier current equipment is used for several other applications besides protection. These are:

   a. Station to station communication. In power station, receiving stations and sub-stations telephones are provided. These are connected to carrier current equipment and conversation can be carried out by means of "Current Carrier Communication".
   b. Control. Remote control of power station equipment by carrier signals.
   c. Telemetering.

REVIEW EXERCISE

Circle the letter (a, b, c or d) that correctly completes each statement:

1. The Carrier Frequency Range is __________________________

a)	25 – 60 Hz	b)	30 – 200 Hz
c)	30 – 500 Hz	d)	100 – 500 Hz

2. The phase comparison system use overcurrent fault detecting relays to compare ____________ at the terminals through the channel.

a)	current directions	b)	relative phase of the currents
c)	both (a) and (b)	d)	neither (a) nor (b)

3. Transmission of the signals for unity system could be ____________________.

a)	through communication cable	b)	through PLC
c)	through radio	d)	all of the above

4. Coupling capacitor provides ____________ impedance to the power frequency and _______________ impedance to the high frequency current.

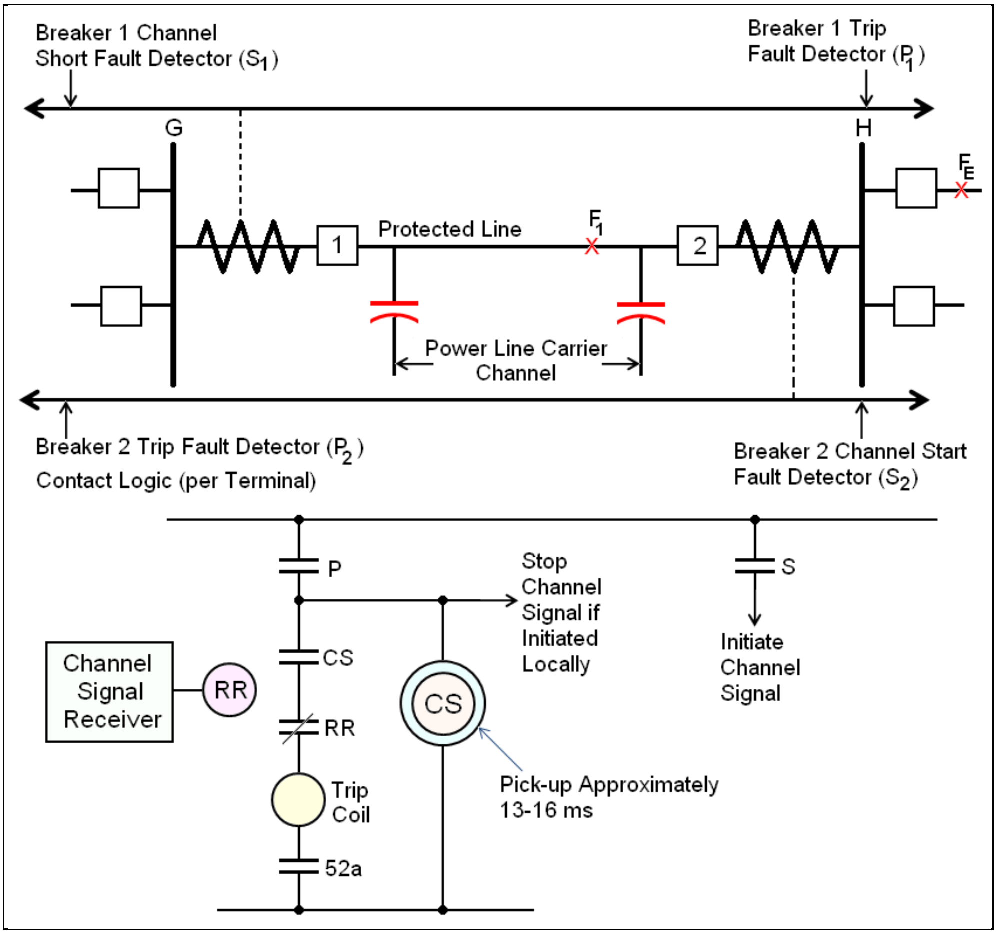
a)	High – High	b)	High – Low
c)	Low – Low	d)	Low – High

5. The- Line Trap provides a ____________ impedance to the power frequency current.

a)	Large	b)	Moderate
c)	Very Large	d)	Negligible

6. The basic principle of directional comparison is to _______________ at the two ends.

Study the diagram shown below, and then answer the following questions:



7. What are the events at Station **G** in case of fault at ($\mathbf{F_E}$)?

a. $\mathbf{P_1}$ Operates, $\mathbf{S_1}$ may or may not operate, but when $\mathbf{P_1}$ operates it prevents transmission of a blocking signal and it will tripe breaker-1.

b. $\mathbf{P_1}$ Operates, $\mathbf{S_1}$ does not see fault and a blocking signal received from station **H** opening

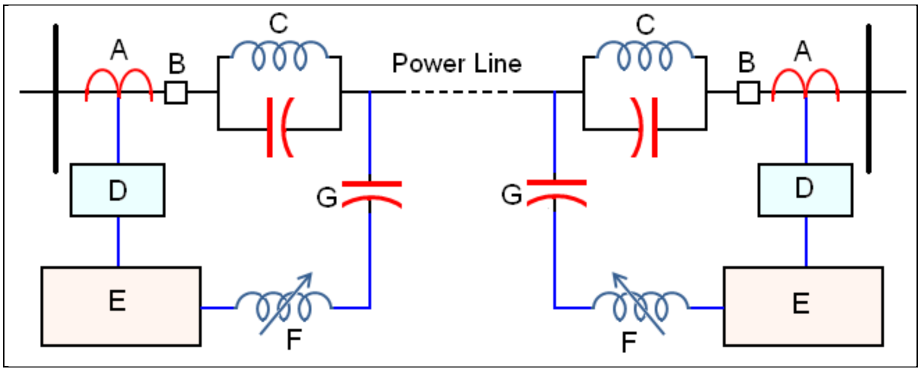
c. **RR-back** contacts and prevent tripping.

d. $\mathbf{P_1}$ Operate, $\mathbf{S_1}$ may or may not operate, but $\mathbf{P_1}$ operation prevents transmission of a blocking signal and breaker-1 will not trip

e. $\mathbf{P_1}$ Operates, $\mathbf{S_1}$ does not see fault and a blocking signal received from station **H** opening

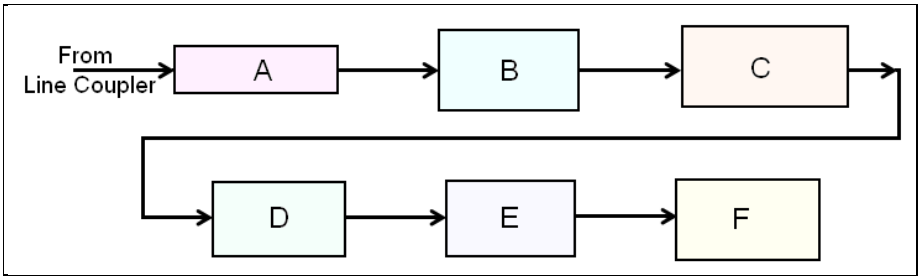
f. **RR-back** contacts and breaker-1 will trip.

8. Match the following items with the letters on the diagram shown below:



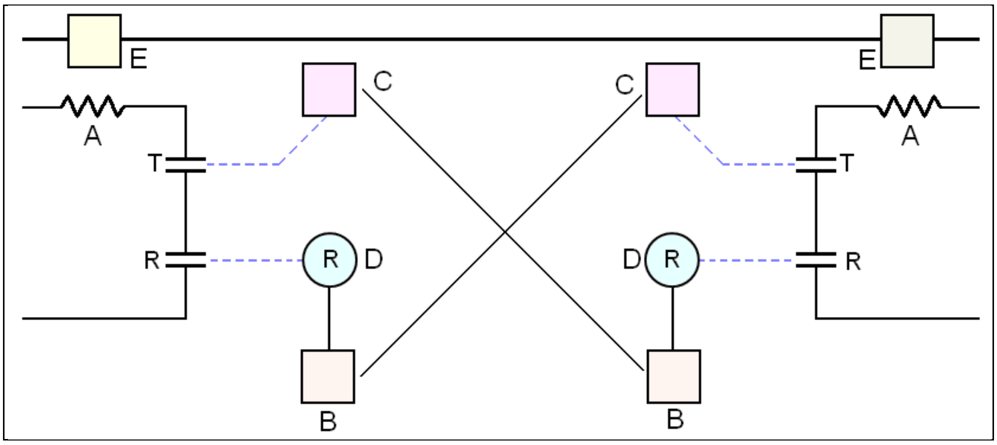
	Line trap
	Coupling capacitor
	Circuit Breaker
	Transmitter and receiver
	Relay
	Line tuner

9. Match the following items of the block diagram of receiving unit with the letters on the diagram shown below:

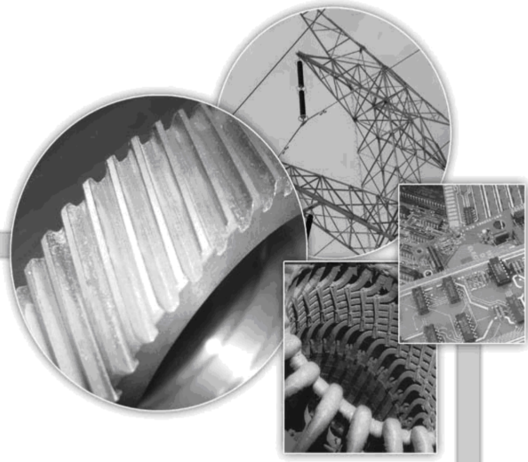


	Level detector		Carrier receiver
	Attenuator		Protective relay
	Band pass filter		Matching element

10. Match the following items of the Permissive Overreach Transferred Trip with the letters on the diagram shown below:



	Receiver
	Transmitter
	Trip coil
	Relay
	Circuit breaker



LESSON 2.4

POWER LINE CARRIER (PLC)

LESSON 2.4
POWER LINE CARRIER (PLC)

OVERVIEW

This lesson introduces power line carrier and its applications in relaying information from one point to another. It covers Power Line Carrier components and their functions for reliable communications through the power line as a medium of transmission.

OBJECTIVES

On completion of this lesson, the trainee should be able to:

- Describe general concepts of Power Line Carrier applications.
- List four methods of communication used in Power Line Carrier application.
- Explain the function of different Power Line Carrier Components in a PLC System.
- Illustrate two types of Capacitor-Coupling Methods for injecting the Power Line Carrier into the transmission line.
- Explain the purpose of the two types of Line Traps.
- Discuss the Line Matching Unit application in the Line Tuner.
- Define Standing Wave and its effect on RF transmission.
- Explain carrier bypassing.
- Describe the operation of a Hi-Coupler in Power Line Carrier application.
- Define the function of Hybrids in Power Line Carrier application.
- Analyze Control Circuits used in Power Line Carrier application.
- Describe the functional blocks in the Transmitter and Receiver.
- Compare Directional comparison with Phase comparison for fault detection in real-life systems.

INTRODUCTION

In the protective relaying application to power systems, the Relay Engineer is confronted with the necessity of providing a channel of communication between two or more system locations for the transmission of Relay "intelligence" from one point to another. His primary concern is to provide adequate Relay protection to detect, locate, and isolate system faults promptly and, at the same time, maintain adequate availability of power to consumers.

The most effective relaying schemes require that the information is available at two or more locations to be compared. Such comparison permits simultaneous tripping of all terminals of a line section. The communication channel provides the necessary link for this comparison of Relay intelligence. When a fault occurs, each location supplies the information for coordination in determining whether the section is to be tripped or left on line.

The selection of the best communication channel for protective relaying is governed by a number of considerations. The distance between stations, nature of terrain, and functions required all affect the selection of the most desirable link. At the present time, the following methods are in common use:

1. **Microwave Radio -** utilizing radio transmitters and receivers operating in the 1700 to 6800 MHz frequency band.

2. **Power line carrier -** utilizing Transmitters and Receivers operating in the 30 to 200 kHz frequency band, and using the power transmission line as the propagation medium for these signals.

3. **Audio tone equipment** - using transmitters and receivers operating in the 600 to 3000 Hz frequency band, utilizing a privately owned or leased pilot wire channel or as modulation on microwave channels.

4. **Pilot wire equipment -** using either 60Hz power frequency or DC signals.

From the preceding, it is obvious that the primary technical difference between the various systems is the area within the frequency spectrum in which they operate.

Each system utilizes different means of signal propagation for optimum performance. For instance, microwave transmission utilizes radio antenna for the transmitted signal, usually concentrated into a “beam” focused and directed to the receiving terminal. Likewise, carrier frequencies could also be transmitted over a pilot wire circuit. However, the usual pilot wire construction would introduce prohibitive losses in transmission. A circuit intended primarily for protective relaying must meet rigid standards of reliability and security against false operation. In addition, many applications require the channel to include facilities for telephone communication, telemetering, load control, frequency control, or supervisory control. Each of these facilities has its peculiar channel requirements that add complexity to the system. Careful consideration must be given to the overall channel requirements and the protective relaying function must of necessity be given top channel priority.

POWER LINE CARRIER CONCEPT

As one of the more important and widely used communication channels in the electric utility field, power line carrier offers a reliable secure means of communicating Relay intelligence from one point to another. The carrier system is composed of transmitters and receivers operating in the frequency range of 30 to 200 kHz with coaxial cable connections to a Line Tuner, and then to the transmission line through a Coupling Capacitor, Fig. 2.4-1.

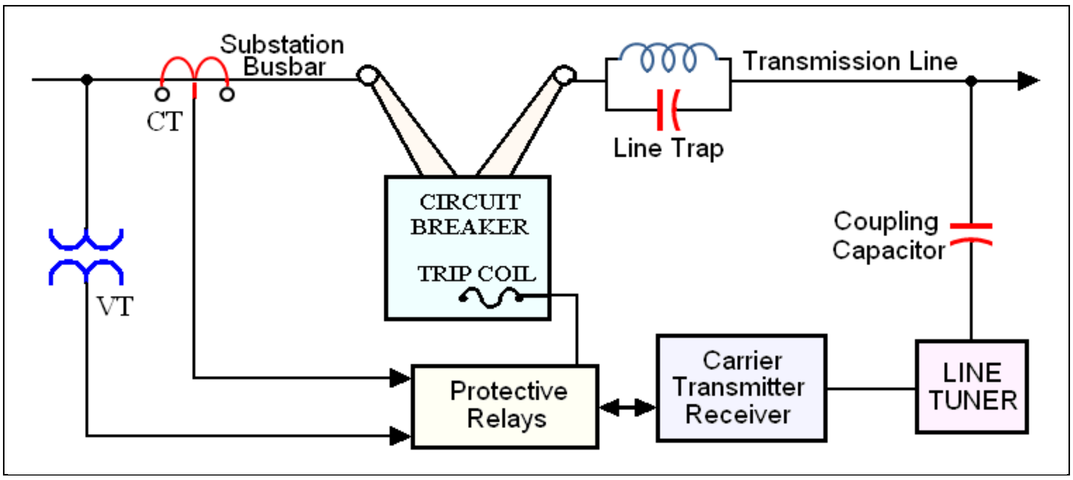


Fig. 2.4-1 Block Diagram of one Terminal Power Line Carrier

Line Traps, which present high impedance to one or more carrier frequencies, serve primarily to prevent a carrier-blocking signal from being shorted to ground by an external fault. Other devices, such as band pass filters and hybrids are used in some applications. A simple block diagram of one terminal carrier-relaying is shown in Fig. 2.4-1.

The protective Relays receive their intelligence from the current and potential transformers in the protected line. Under fault conditions the Relays operate, initiating a signal in the carrier transmitter, which passes through the Line Tuner and Coupling Capacitor to the transmission line and then over the line to the remote terminal. Comparison of this signal with the Relay status at the remote terminal determines whether the line section is to be tripped out or kept intact on external faults. The Line Trap prevents the carrier signal from being grounded by an external fault.

POWER LINE CARRIER CHANNEL

Power line carrier channels are used providing many vital links in the operation of nearly every major electric utility system. More and more functions are added to the carrier channel to provide for telephone service, telemetering, load frequency control, and supervisory control. On some of the larger systems, the problem of frequency assignments for all the various functions becomes a major consideration. Supplemental tone channels can often provide relief in these cases. Carrier channels that provide for such vital functions as protective relaying, voice communication, telemetering, supervisory control, and load frequency control have certain channel requirements, which are peculiar to each function.

In general, power line carrier is normally recommended on lines of medium or high voltage transmission and 10-200 miles in length. For circuits less than 10 miles in length, audio tones, and pilot wire are usually the preferred medium, where multi-function service is required beyond the capacity of a carrier system, a combination of carrier, pilot wire, tone, or microwave is considered.

POWER LINE CARRIER COMPONENTS IN PLC SYSTEM

COUPLING CAPACITOR

The purpose of the coupling network is to achieve transfer of energy to and from the transmission line at carrier frequency and simultaneously reject the flow of power frequency energy. This is achieved by the filter action or resonance. The coupling capacitor provides the means for injecting the carrier signal into the line. The capacitance value is selected to provide high impedance to 60Hz power current and low impedance to high carrier frequency signals. Modern practice Prefers Line-to-Ground coupling as shown in Fig. 2.4-2(a) because of installation economics as compared to Line-to-Line coupling. Fig. 2.4-2(b) shows the schematic diagrams of the two capacitor-coupling methods.

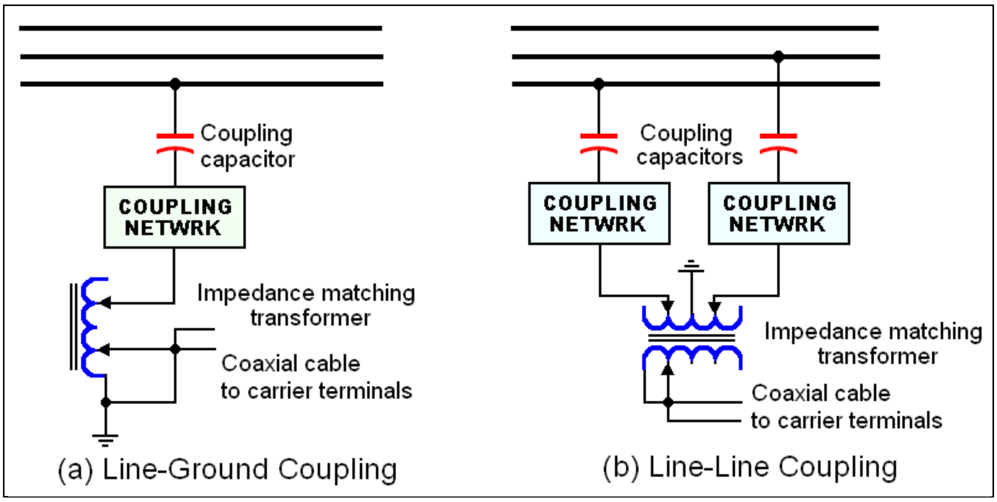


Fig. 2.4-2 Capacitor-Coupling Methods

LINE TRAP

The purpose of the Line Trap is to confine the injected carrier signal to the desired conducting transmission line between Transmitter and Receiver. Any loss to the adjacent bus or line results in a weakened signal at the receiver, which may then be insufficient to operate the protection scheme. The simplest type of Line Trap as shown

in Fig. 2.4-3, consists of a large coil (inductor) capable of carrying high load current. It must also be able to withstand very high values of fault current for short periods of time. The inductor is sized to provide reasonably high impedance to the carrier signal (30-500 kHz). At the same time, the inductor must offer Zero or very low impedance to the 60Hz power current flow. The chosen inductor value is usually quite small (≈2mH), and the inductive reactance is given by:

$X_L(60Hz) = 2\pi\, f\, L = 2\pi\ (60Hz)\ (2mH) \approx 0.75\Omega$

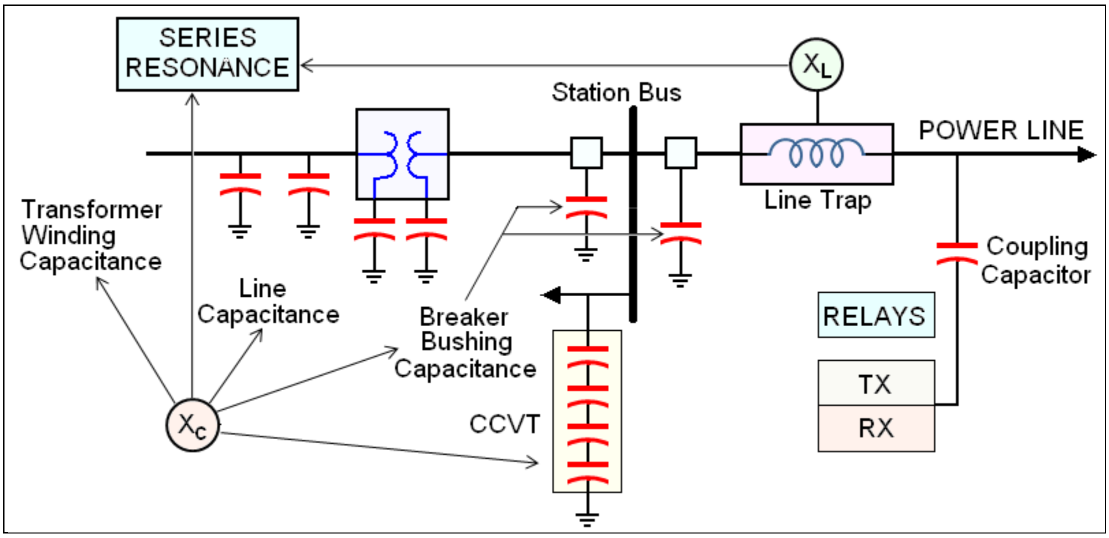


Fig. 2.4-3 Line Trap, XL in Series Resonance
With X_C of Line, Breaker Bushings, and CCVT

At 60Hz, a 2mH inductor produces an inductive reactance of approximately 0.75Ω. However at the carrier frequency of, say, 100 kHz the impedance of this inductor will be relatively high (≈1250Ω).

$X_L(100kHz) = 2\pi\, f\, L = 2\pi\ (100kHz)\ (2mH) \approx 1257\Omega$

Experience has shown that in certain installations, the inductance can create a high frequency series resonance with capacitive circuits on the bus side, such as CCVTs, line capacitance, transformer winding capacitance, and breaker bushing capacitance. The consequence of this is a drastic reduction in impedance and loss of carrier signal to ground as shunt loss. As shown in Fig. 2.4-3 and Fig. 2.4-4 the passive Line Trap consist of a tuned resonant circuit with inductance and capacitance in series or

parallel, respectively. The value of inductive reactance is chosen to be exactly the same as that of the capacitive reactance at the desired resonant frequency.

Within the resonant circuit, current flows from the inductor to charge the capacitor, and then in the next half cycle it is discharged from the capacitor back to the inductor. The resonant current oscillates continuously between inductance and capacitance, but draws little current from the power supply. If the circuit contained absolutely no resistance at all, the parallel resonant circuit provides infinite impedance to the flow of current. In practice resistance does always exist but the circuit still provides high impedance at the tuned frequency.

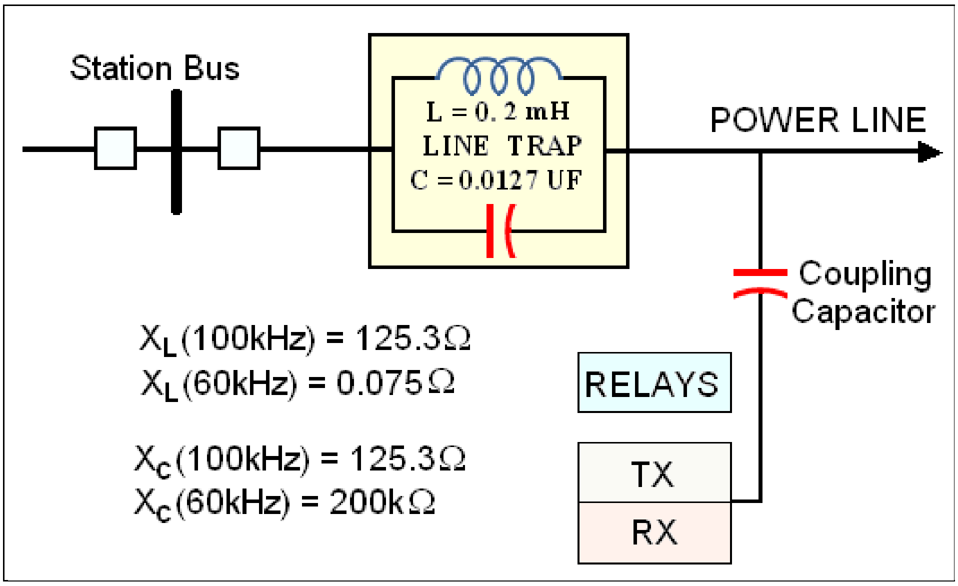


Fig. 2.4-4 Line Trap, XL = Xc in Parallel Resonance at Carrier Frequency (fr = 100kHz)

TWO-FREQUENCY LINE TRAPS

Many times, it is desirable to install Line Traps for trapping two frequencies, as shown in the schematic of Fig. 2.4-5. A single-Line Trap can be very effectively converted for two-frequency operation.

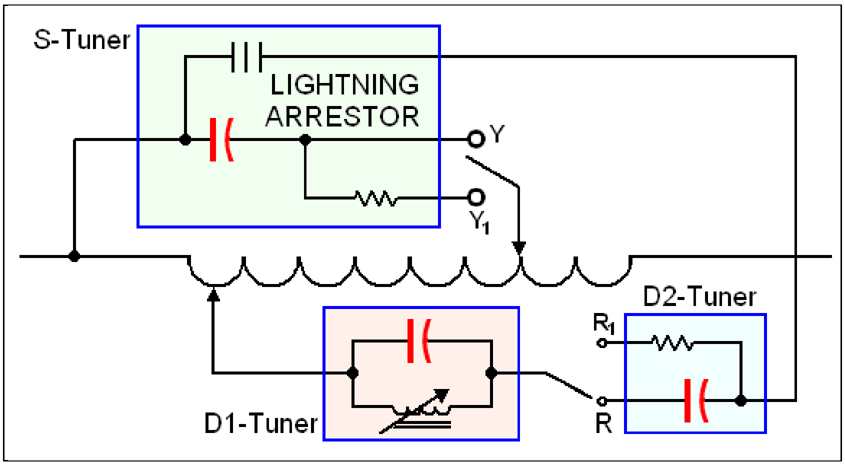


Fig. 2.4-5 Two-Frequency Line Trap Connections

For a two-frequency trap, the impedance available at each of the two resonant frequencies is approximately one-half that of a single-frequency trap using the same inductance value. In applying two-frequency traps, the number of variables that must be adjusted is greater

LINE TUNER

As shown in Fig. 2.4-6 the simplest type of Line Tuner consists of a series inductor sized to give inductive reactance equal to the capacitive reactance of the coupling capacitor at the specific carrier frequency, (say 150 kHz).

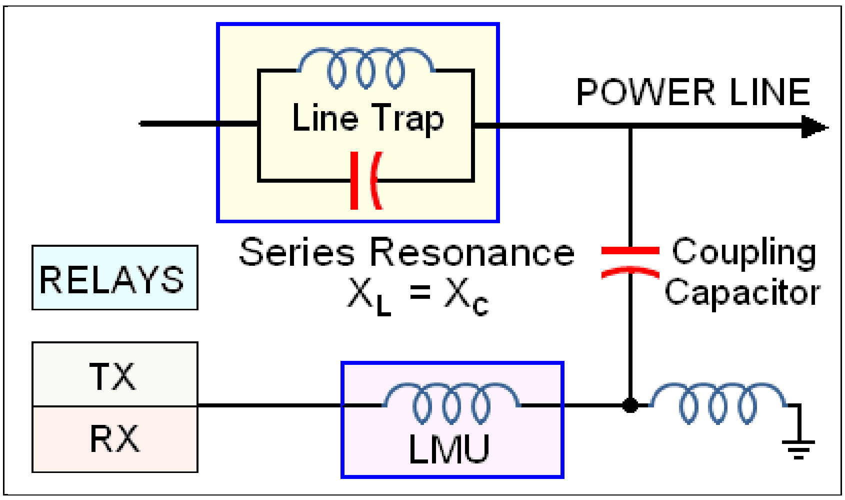


Fig. 2.4-6 Simple Line Tuner (Line Matching Unit)

This provides series resonance, with very low-Q to the 150kHz current. However, one single carrier frequency is not usually enough. Quite often we will transmit, say at 150 kHz, and receive at, say 112 kHz. In this case the tuner must provide low impedance coupling at both the operating frequencies.

In order to achieve two frequencies, the tuning circuit becomes more complex, as shown in Fig. 2.4-7. A combination of inductors and capacitances is arranged in series and parallel. Parallel resonance providing high impedance at its designed frequency blocks the undesired power current flow.

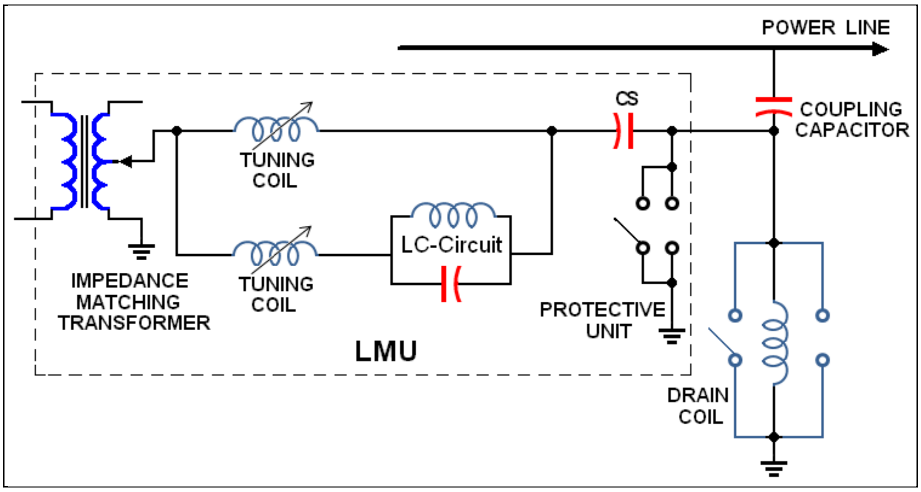


Fig. 2.4-7 Two-Frequency Line Tuner (Line Matching Unit)

In contrast, series resonance provides low impedance by combining different circuit elements, some of which are in parallel resonance and some in series resonance. We can have the tuned circuit to block certain frequencies and pass others.

Fig. 2.4-8 shows the panel layout for two-frequency line tuner assembly. As shown in Fig. 2.4-9, the tuning equipment includes a multi-tapped impedance matching transformer at the input end. This is needed to overcome any impedance mismatch that may exist between the transmission line and the power line carrier equipment. A coaxial cable connects the impedance matching transformer in the LMU to the carrier equipment.

If the impedances were not matched, the carrier system would suffer a reduction in signal power due to reflectivity. When the signal passes into any part of the system

where the impedance suddenly changes, some of that signal is reflected back. This reflected power reduces the value of power that is sent down the line to the receiver.

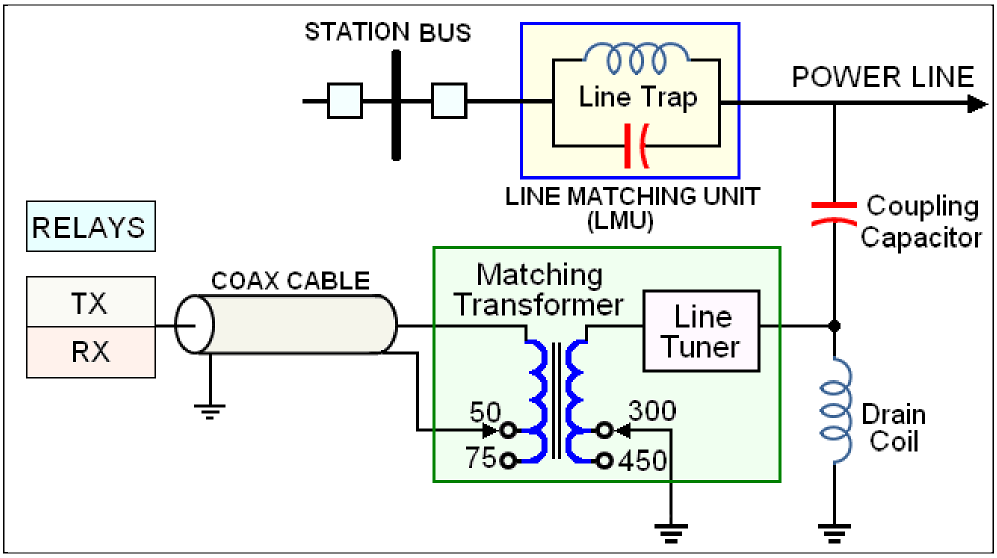


Fig. 2.4-8 Impedance Matching Transformer

As shown in Fig. 2.4-9, under certain conditions the reflected signal may be in phase with the original signal producing a "Standing Wave”. If this happens, the energy would be radiated and lost into space, instead of being transferred down the transmission line. In the communications circuit, reflection will occur at any point where a discontinuity in impedance takes place, such as a second line tapped into the transmission line or between the coaxial cable and line tuner.

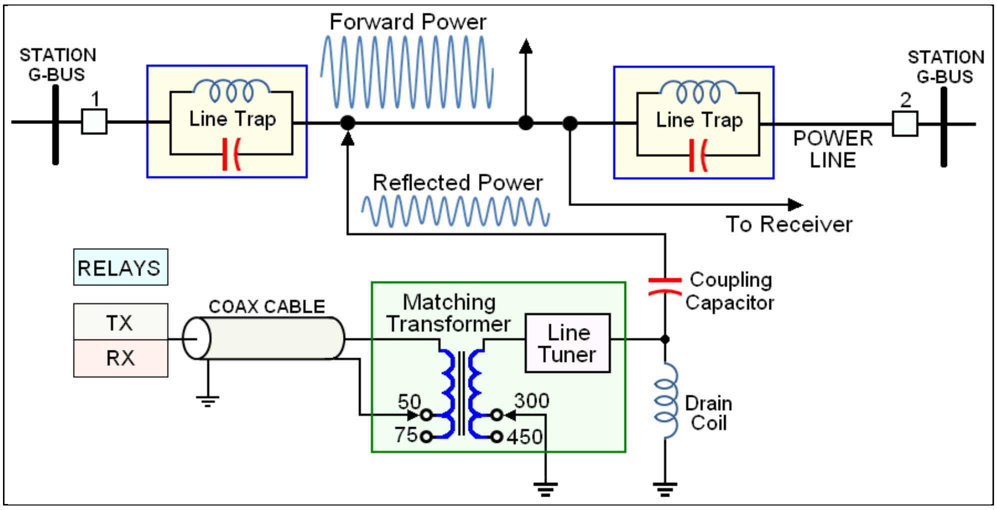


Fig. 2.4-9 Forward and Reflected Power

In order to prevent this loss, it is important that impedance mismatch be reduced as much as possible. The LMU taps should initially be set to the anticipated value of line impedance (≈300-400Ω) and the impedance of the coaxial cable (≈50-75Ω).

BYPASSING

Power line carrier systems frequently require bypassing of energy around an open circuit breaker, a transformer, or between lines of different voltages. This bypassing may involve the transfer of energy for a single channel or it may require the other extreme, involving the transfer of the entire carrier spectrum. The carrier bypass connection is usually made at coaxial cable level between the two coupling points, as shown in Fig. 2.4-10(a).

Where the coupling points are close together, it is common practice to utilize a well-insulated, high impedance, open wire connection between these points that is known as Short Bypass. Such a bypass for a single frequency need only one series inductance capable of resonating the combined reactance of the two coupling capacitors, as shown in Fig. 2.4-10(b). Such bypasses cannot accept the addition of terminal equipment at the coupling location.

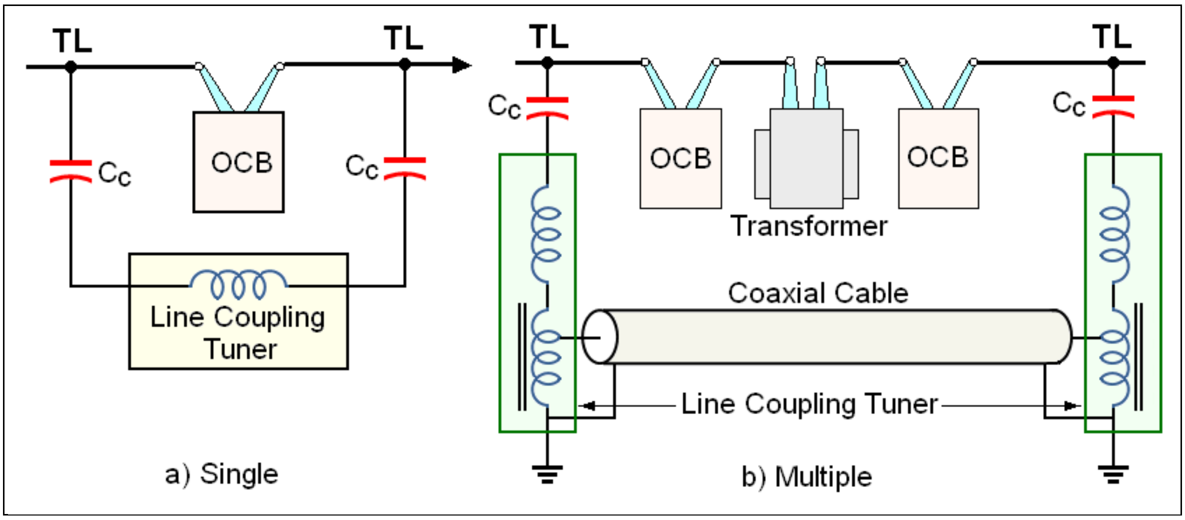


Fig. 2.4-10 Equipment Bypassing

ACCESSORY EQUIPMENT

HI-COUPLER

In a carrier installation involving the use of one or two channels on a transmission line section, the use of a standard capacitance coupling is suitable, and the adjustments provided in the line tuner are adequate to resonate these units, especially when the line tuner is located close to the coupling capacitor. In installations where more than two carrier channels are involved, the high capacitance coupling capacitor is used in conjunction with a Hi-Coupler, providing the broad-band tuning required. The Hi-Coupler, with its associated impedance matching unit, approximates a high-pass filter "T" section.

The Hi-Coupler is mounted in the base of the coupling capacitor. These Hi-Couplers are also used to provide a bypass around a discontinuity in the transmission line. The Hi-Coupler unit includes an impedance matching transformer and is rated at 100W continuous providing ample reserve capacity.

HYBRID COILS

Whenever energy at two or more frequencies combines in a nonlinear circuit, such as a transmitter output circuit or a Receiver input circuit, mixing takes place and products other than the original frequencies are generated. These spurious frequencies are called "inter-modulation products" and can cause serious interference within the carrier band or the audio band. In setting up power line carrier channels and assigning frequencies, especially channels that are closely spaced, it is important to know something about the nature of these product frequencies in order to predict their effects to some extent. The number and level of the products produced depends upon a variety of things such as the number of transmitters and receivers involved, their location or degree of isolation from one another, as well as their electrical characteristics. As shown in Fig. 2.4-11, the RF Hybrid consists of a RF transformer and a balance network that includes inductance, resistance, and capacitance. One winding of the transformer is center tapped and the balance network is connected

between the center tap and common ground. The circuit is so arranged that power from one input circuit divides between the load and the balance network and the power that is fed into the balance network results in cancellation of the voltage across the other input circuit and vice versa.

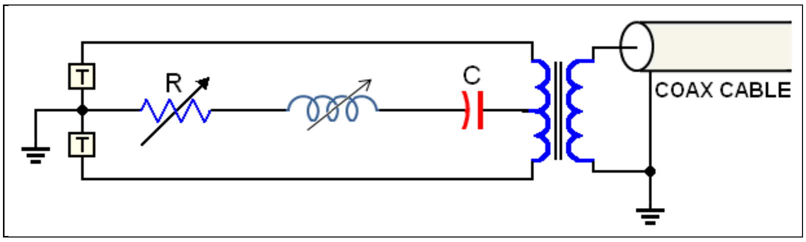


Fig. 2.4-11 RF Hybrid Unit

The proper selection of operating frequencies will also help to eliminate many troubles. For instance, if it is desired to have several telemetering channels along with an on/off channel or where a channel failure alarm is required, the frequency of this latter channel should be selected so that it will fall between the Inter-modulation products of the telemetering channels. For instance, if the telemetering channels are spaced every kHz, they produce Inter-modulation products every kHz on either side of their carriers, so that on/off channel should have a frequency that falls between the signals to eliminate interference from them. Although installed in all cases, there is no need for RF Hybrid circuits where this rule can be followed.

TERMINAL CONSIDERATIONS

CONTROL CIRCUIT

The carrier frequency energy is transmitted from the carrier transmitter to the Line Tuner on a coaxial cable line. It is usual practice to install the Line Tuner in close proximity to the Coupling Capacitor and the short connection between these components seldom introduces any appreciable losses. The connection between the Line Tuner and the carrier Transmitter/Receiver may be considerable length and the attenuation loss should be considered in the overall design of the system. The

connection between the Line Tuner and the Transmitter/Receiver should therefore be made as short as possible with due consideration to the possibility of inductive interference introduced into the coaxial cable by proximity of power conductors and other apparatus.

The basic relaying control circuits are usually of low resistance and adequate insulation level for this type of service and require no special treatment when used with carrier equipment. When telephone facilities are provided with the carrier units and the telephone lines are of any appreciable length, they should be provided with surge protection. All such lines should be of twisted in pairs to avoid the effects of stray inductive coupling within the cable.

POWER SUPPLY

For protective relaying applications of carrier equipment, an unfailing power supply is mandatory, as the equipment must operate at times when the commercial supply has failed due to a fault or other disturbance. As most electric utilities and substations maintain a battery supply for control purposes, the carrier equipment is designed for operation from the station battery. Units are available for 48, 125, or 250 VDC.

The equipment is designed to tolerate variations in voltage encountered in the normal charge/discharge cycling of the battery circuit. The AC ripple introduced by the charging apparatus should be considered as a source of noise, especially when voice communication on the carrier channel is involved. In addition, any apparatus utilizing semiconductors is susceptible to surges in the battery circuit and this should be considered in design of the carrier system.

COAXIAL CABLE

Power line carrier equipment is designed to utilize standard 50 and 75Ω coaxial cable.

CARRIER TRANSMITTER AND RECEIVER

The selection of the proper carrier Transmitter and Receiver to be used for protective relaying is governed primarily by the relaying system using the channel. If other functions are to be performed by the carrier channel, the requirements of each function must be considered and the equipment provided with relaying priority circuits so that a Relay operation can take over the channel instantly. Line attenuation and Signal-to-Noise ratios (S/N) must also be considered. Transmitter output power and Bandwidth are other considerations. The speed of operation of a carrier-relaying system is a function of the channel bandwidth and the output power of the transmitter directly affects the bandwidth. Selection of a carrier Transmitter/Receiver should logically begin with outlining the requirements, as follows:

1. Services Required

(a) Relaying
- Phase Comparison
- Over-reaching blocking
- Over-reaching tripping
- Under-reaching tripping
- Remote trip (for transformer protection)
- Other types

(b) Telemetering
- Impulse rate
- Other types
- Frequency

(c) Supervisory Control
- Point-to-point
- Multi-station

(d) Maintenance (Push To Talk) Voice Communication

2. Line attenuation
3. Signal-to-Noise ratio requirements
4. Type of mounting (switchboard, rack, cabinet, indoor or outdoor)
5. Available power supply (DC/AC)
6. Accessories (reserve signal test, voice adapter, telephone handset, etc)

7. Operating frequency (50/60Hz)
8. Other carrier frequencies on the channel (Single/Multiple)

The first consideration in applying a Transmitter/Receiver to a carrier system is the provision of protective relaying function. Some systems utilize an on/off keying of the carrier frequency. Others transmit a signal only when blocking is required. Still others use a continuous signal that is shifted in frequency to transmit the intelligence. As the specific type of transmission is indicated by the relaying scheme used, this aspect will be discussed under "Carrier Relaying Systems".

The most closely related auxiliary functions applied to a carrier system used primarily for relaying, is maintenance of Telephone Service and a Signal Test. Aside from the relaying requirement consideration, the most important requirement of the Transmitter/Receiver is its ability to generate a carrier signal of sufficient power to override the Line Attenuation, line noise, and other interfering signals. Its bandwidth should be as narrow as possible to permit close spacing of adjacent channels.

The Receiver should be capable of providing an adequate output to operate Receiver Relays under the line conditions of attenuation and noise. Bandwidth is very important to be considered when using the equipment on lines having other carrier channels. The spacing of frequencies between channels determines the number of channels that can be made available in the carrier frequency spectrum. The frequency selected also has an important bearing on line attenuation.

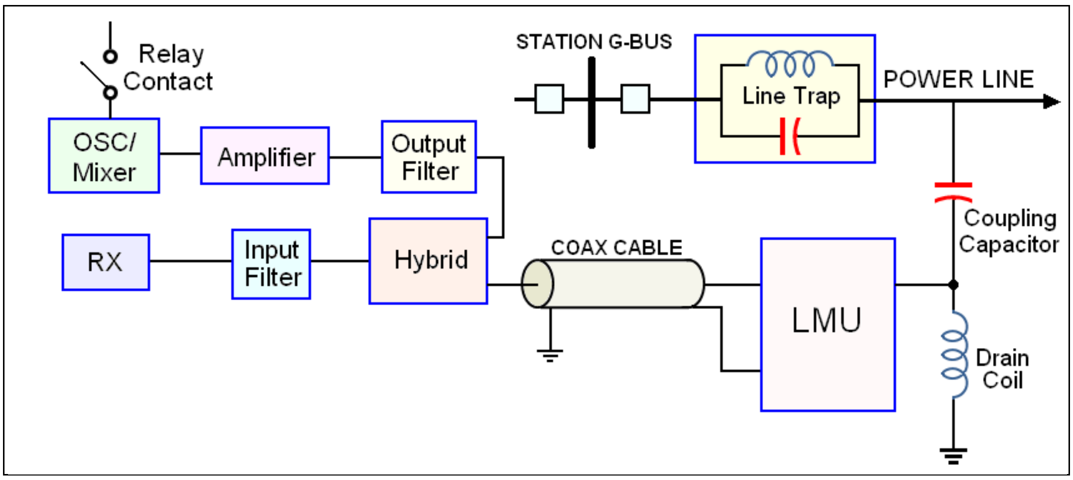


Fig. 2.4-12 Block Diagram of PLC Transmitter/Receiver

The block diagram in Fig. 2.4-12 shows the basic components of the Transmitter. The initial signal is produced in the Oscillator/Mixer block at precisely the desired frequency. The Oscillator signal is passed through the Amplifier block in order to boost the power (say 10W) sufficient for transmission to the Receiver at the far end of the line. The boosted signal passes through the Output Filter that is tuned for the specified operating frequency.

Finally, it passes through a Hybrid unit and the Coaxial Cable to the line coupling equipment. The Receiver equipment, as shown in Fig. 2.4-13, is similar. The incoming signal passes through the Hybrid and the Input Filter. The signal may then be processed and fed into a "Discriminator" other similar_device that recovers the message and triggers action such as Breaker Trip.

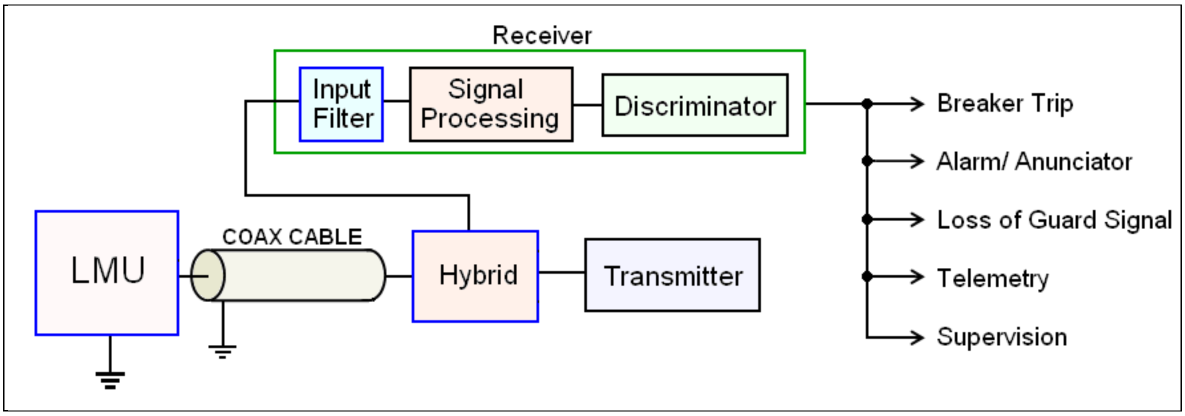


Fig. 2.4-13 Block Diagram of PLC Receiver

CARRIER RELAYING SYSTEMS

Any carrier-relaying system (microwave, tone, or pilot wire) is basically a "differential" relaying concept where currents, voltages, or power flow are compared between two points to determine whether a fault or other undesirable condition is internal or external to the protected zone. If internal, the objective is to trip all breakers associated with the faulted section simultaneously at high speed. If the fault is external, the normal objective is to prevent the associated breakers from tripping.

In the standard transformer, generator, or bus differential scheme, the comparison of currents or voltages is made directly by the elements of the differential Relay and no separate "intelligence" channel is required.

If it were practical to extend this scheme to widely separated points on the power system for transmission line protection. The distances involved are too great for this type of operation; hence, techniques using the various communication channels were developed.

When using a transmission line as a channel for carrier-relaying purposes, one fundamental rule is paramount that the channel must provide the maximum reliability to trip when required and security not to trip when not required.

Under internal fault conditions, the carrier channel may be short circuited or otherwise affected so that a signal could not be reliably transmitted to the receiving point. For this reason, carrier-relaying systems are usually designed to transmit a carrier signal for blocking tripping and the absence of the signal under fault conditions permits tripping of the line section at high speed. The blocking signal used under external fault conditions must be established before the tripping units operate. This is especially critical when the external fault clearance by other Relays causes an instantaneous reversal of power flow through the protected line, such as in parallel line operation.

The tripping units at one end must reset before the remote carrier start units reset, and the carrier start units at this first end must establish carrier before the remote carrier trip units operate. This timing coordination is an important consideration in the relaying scheme.

There are two basic Carrier-Relaying Systems in general use:

SUMMARY

- The primary responsibilities of the Relay Engineer is to provide adequate Relay protection, detect, locate, and isolate system faults promptly and maintain adequate availability of power to consumers.

- The selection of the best communication channel for protective relaying is governed by the distance between stations, nature of terrain, and functions required by the most desirable link.
- Pilot wire equipment uses either 60Hz power frequency or DC signals for communication channel.
- The Line Trap prevents the carrier signal from being grounded by an external fault.
- The coupling capacitor provides the means for injecting the modulated carrier signal into the transmission line.
- Line-to-Line coupling is more expensive as compared to Line-to-Ground coupling.
- A passive Line Trap consists of a tuned resonant circuit with inductance and capacitance in parallel, so that the inductive reactance is the same as capacitive reactance at the desired resonant frequency.
- For a two-frequency trap, the impedance available at each of the two resonant frequencies is approximately one-half that of a single-frequency trap using the same inductance value.
- The purpose of the Line Matching Unit is to overcome any impedance mismatch that may exist between the transmission line and the power line carrier equipment.
- The carrier bypass connection is usually made at coaxial cable level between the two coupling points around an open circuit breaker, a transformer, or between lines of different voltages, transferring the entire carrier spectrum.
- RF Hybrid consists of a RF transformer and a balance network that includes inductance, resistance, and capacitance.
- RF Hybrids are used to isolate Transmitters and Receivers and to minimize interference due to harmonics of the carrier or inter-modulation frequencies.
- The connection between the Line Tuner and the Transmitter/Receiver should be made as short as possible with due consideration to the possibility of inductive

interference introduced into the coaxial cable by proximity of power conductors and other apparatus.

- When telephone facilities are provided with the carrier units and the telephone lines are of any appreciable length, they should be provided with surge protection and be twisted in pairs to avoid the effects of stray inductive coupling within the cable.
- The output power of the transmitter directly affects the bandwidth of a communication channel.
- Any carrier-relaying system is basically a "differential" relaying concept where currents, voltages, or power are compared between two points within the protected zone to determine whether a fault is internal or external.
- Directional comparison method is used for phase faults and Phase comparison for ground faults.

GLOSSARY

PLC:	Power Line Carrier.
S/N:	Signal-to-Noise Ratio.
TCU:	Transistorized Control Unit.

REVIEW EXERCISE

1. The primary responsibilities of the Relay Engineer are to provide adequate Relay protection, ______, ______, and _____ system faults promptly and maintain adequate availability of ___________________.

2. The three factors that govern the selection of the best communication channel for protective relaying, are:
   - ___________________________
   - ___________________________
   - ___________________________

3. Transmitters and Receivers in a power line carrier system operate in the ___________kHz frequency band, and using the power transmission line as the propagation medium for these signals.
   a) 30-200 b) 30-3000 c) 300-3000 d) 300-5000

4. The communication channel facilitates for five types of signals:

   ___________________ _______________ ___________

   ___________________ ___________________

5. The transmission line is coupled to the Line Tuner through a _______.
   a) Resistor b) Capacitor c) Inductor d) Hybrid

6. Power Line Carrier is normally recommended on lines of medium or high voltage transmission __________ miles in length.
   a) 1-10 b) 10-20 c) 10-200 d) 1-100

7. The coupling capacitor is selected to provide high impedance to 60Hz power current and low impedance to high frequency carrier. True or False

8. The inductor in a Line Trap is sized so as to provide reasonably high impedance to the carrier signal (30-500kHz) and at the same time must offer very high impedance to the flow of 60 Hz power line current.True or False

9. The impedance of 1mH inductor at a carrier frequency of 100 kHz is approximately _____Ω.

   a) 0.628 b) 6.28 c) 62.8 d) 628

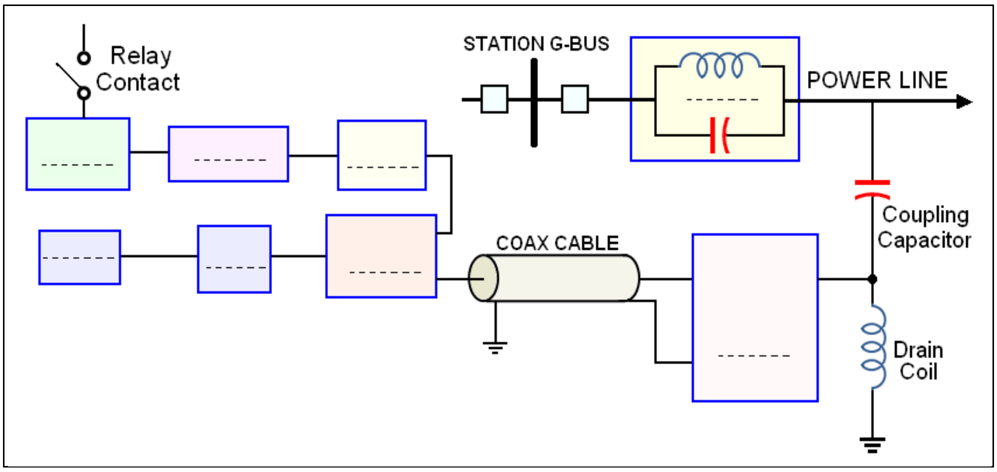
10. The two types of standard coaxial cables used in power line carrier equipment are ____Ω & ____Ω.

11. The carrier-relaying operating speed is a function of the channel _________.

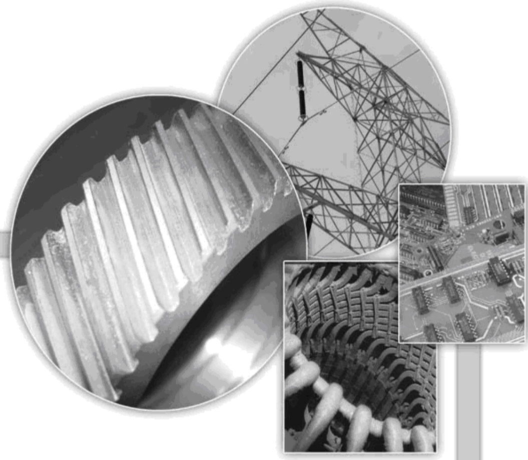
   a) Frequency b) Bandwidth c) Both of above d) None of above

12. Oscillator/Mixer and the Discriminator are parts of the Receiver. True or False

13. Given block diagram for carrier-relaying equipment. List the names of the functional components.



14. If the fault is internal or external, the objective is to trip all breakers associated with the faulted section simultaneously at high speed. True or False



LESSON 2.5

INTRODUCTION TO LIGHT THEORY

LESSON 2.5
INTRODUCTION TO LIGHT THEORY

OVERVIEW

This course introduces theory of light, properties, and its propagation at different wavelengths and frequency. The participants will learn the theory of basic optical mechanism defining light reflection, refraction, absorption, dispersion and scattering, Acceptance Angle, Acceptance Cone, Numerical Aperture, Snell's law, and Critical Angle. The trainees perform relevant tasks at the end of each lesson to enhance their theoretical knowledge and troubleshooting skills.

OBJECTIVES

Upon completion of this lesson, the trainee should be able to:

- Explain the particle theory of light.
- Describe the electromagnetic spectrum and visible light portion.
- Identify the light velocity and light wavelength.
- Describe the light properties.
- Explain the amount of energy in a photon and light power.
- Define the light reflection, refraction, absorption, dispersion, and scattering.
- Explain the basic optical mechanism.
- Define Acceptance Angle, Acceptance Cone, Numerical Aperture, Snell's law, Critical Angles.

INTRODUCTION

Light wave energy can be launched into and will propagate through, optical transmission lines. Such transmission lines are referred to as optical waveguides, light guides, or optical fibers. As in transmission lines in other technologies, e.g., metallic conductors or radio frequency (microwave) waveguides, the nature of light wave transmission lines is to confine the light rays within the boundaries of the transmission line itself. It is possible to launch analog or/and digital information through light energy into optical fibers. As in any transmission system, the process will include transmission losses and various forms of distortion may be introduced into the light wave signals themselves.

PARTICLE THEORY OF LIGHT

Light can be described as extremely rapid moving streams of electromagnetic particles. These particles are called PHOTONS. A photon is a bundle of energy if it does not move, it does not exist. The amount of energy in a photon varies depending on the energy levels. The energy level in a photon depends upon the frequency and the wavelength of light. Wavelengths that are shorter and have a higher frequency have more energy in their photons. For example, Ultra-Violet rays have shorter wavelengths than Infra-Red rays and therefore have higher photon energy.

UNIT FUNDAMENTALS

Like a radio wave, light is in the electromagnetic spectrum, as shown in Fig. 2.5-1. The wavelength of a light wave is related to its frequency. At light wave frequencies, which are designated in Terahertz (10^{12}Hz), it is much more convenient and practical to use wavelengths, exclusively.

Visible light is electromagnetic radiation that can be detected by the human eye, but visible light is only a very small part of the electromagnetic spectrum.

Both Infra-Red and Ultra-Violet radiation are often referred to as light, although they are outside the range that the human eye can detect.

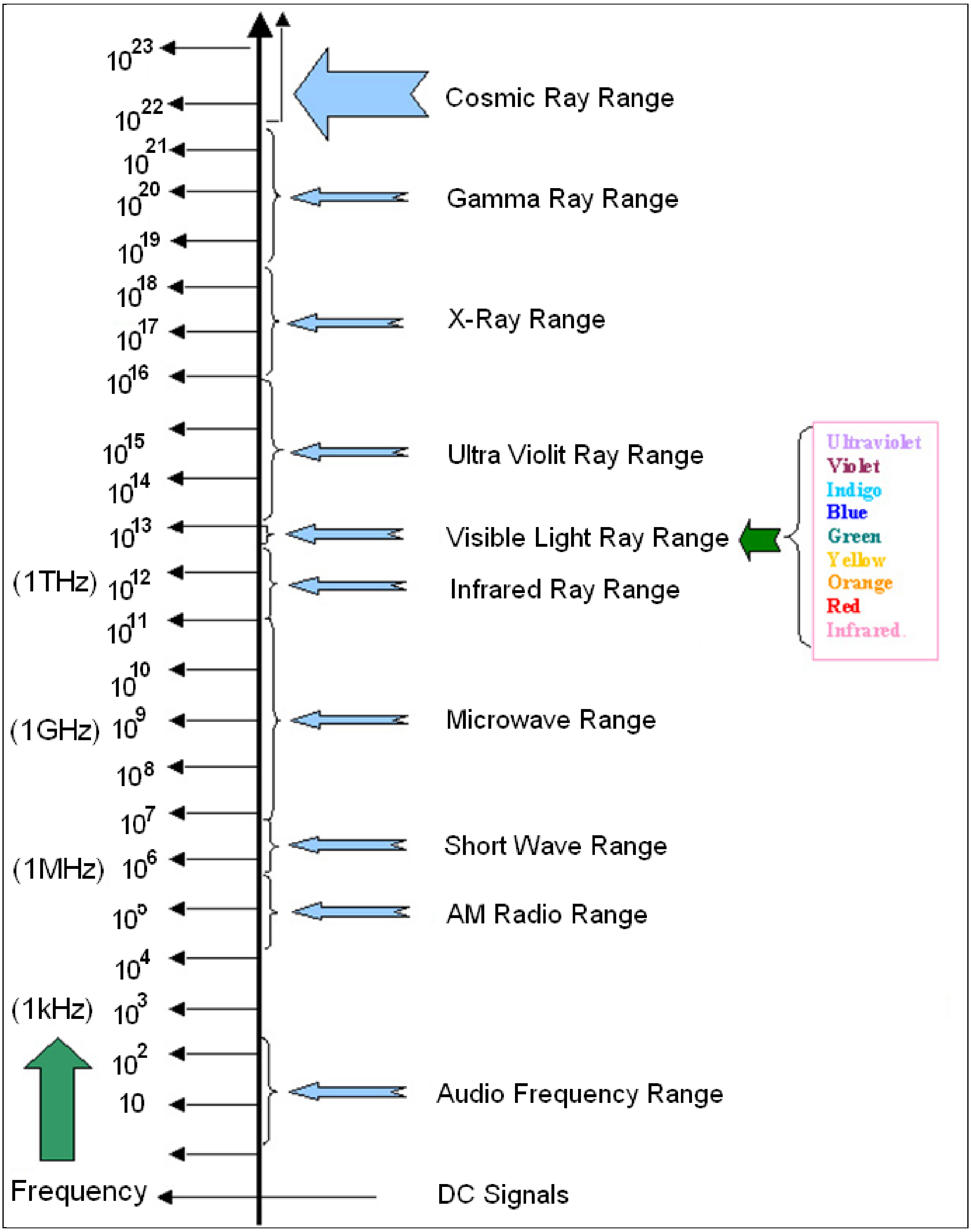


Fig. 2.5-1 Electromagnetic Spectrum

LIGHT VELOCITY

The number of waves that pass a given point per second is called the frequency of the wave. The frequency of visible light more than 10^{13}Hz is very large unit. The velocity of light (c) is 3×10^{8} meter/sec.

LIGHT WAVELENGTH

The wavelength of light (X) is the distance traveled by an electromagnetic light wave during one cycle. Light wavelength (λ) is calculated by dividing the velocity of light in a vacuum (c = 300000 km/s) by the light frequency (f).

$$\lambda = \frac{c}{f}$$

The velocity of propagation (the speed of transmission) is a factor in determining the wavelength of a wave, but it will be different for a wave of a given frequency in different media. For example, a light wave of a specific frequency will travel at a different speed in glass than it will in air and consequently it will have a different wavelength in glass than it will in air, even though the frequency of the light wave remains unchanged. Within the same medium, waves of different frequencies will travel at different speeds also and thus they will have different wavelengths.

At light wave frequencies, wavelengths are very short indeed. We use the micron (μ) to denote a millionth (10^{-6}) of a meter. The nanometer (nm) is $l0^{-9}$ of a meter. The wavelength may be measured in a unit called an Angstrom (A).

$$10\text{A} = 1\text{nm} = 10^{-9}\ \text{m}$$

The term more frequently used in light wave transmission to denote wavelength, however, in the nanometer (nm) or micrometer (μm). Fig. 2.5-2 shows light wavelength spectrum.

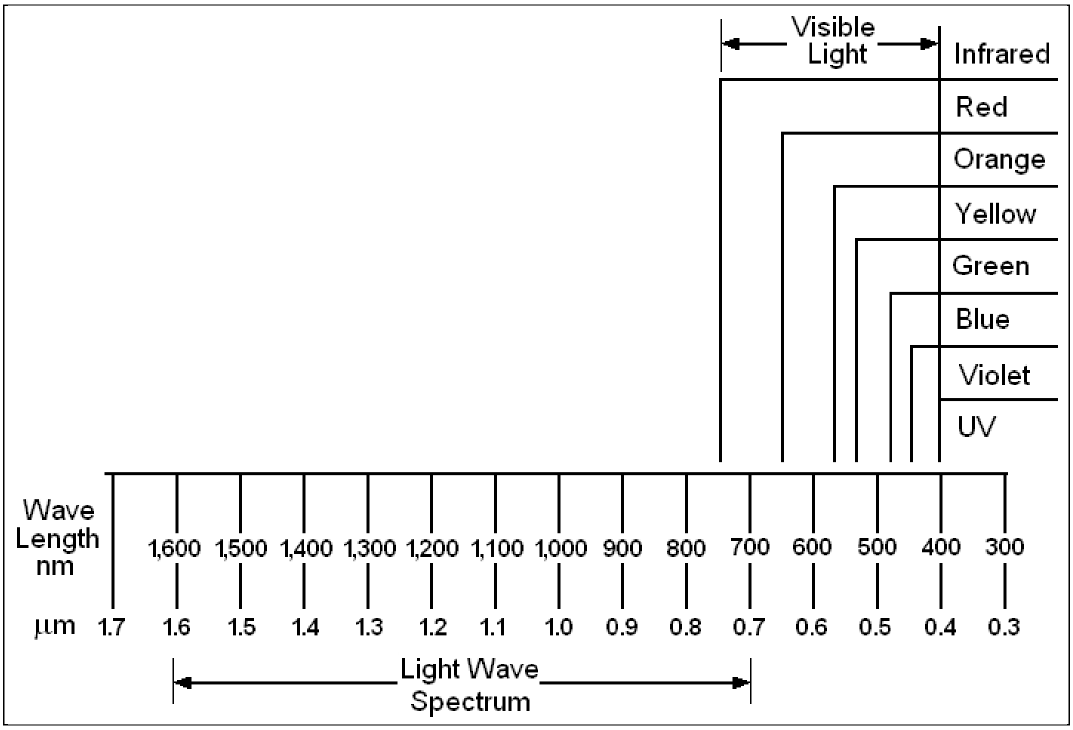


Fig. 2 5-2 Visible Light Spectrum and Wavelength

PROPERTIES OF LIGHT

Like all electromagnetic radiation, light is a form of energy and can be converted into other forms of energy. When light strikes certain materials, those materials give off electrons. This transfer of light energy to electrical energy is called the Photoelectric Effect. Since all light travels at the same speed in air or vacuum and each color has a different wavelength, it follows that each color has a discrete frequency. In the visible spectrum, light wavelength determines the colors we see.

Ultra-Violet (UV) wavelengths are below the visible spectrum and are not detectable by the human eye. Infra-Red (IR) wavelengths are above the visible spectrum, which also makes them invisible. Both visible and invisible electromagnetic waves contain electromagnetic power that can be detected electronically. The entire light spectrum can be used for fiber-optic communications. Light can be emitted from bodies that have been heated until they glow. In the incandescent light bulb, using an electrical current through the filament of the bulb heats the filament. The heat transfers more energy to the atoms of the filament than they usually have and the excess energy radiates as light. In a laser, atoms are given extra energy that they store until they emit

light. A light wave moves away from its source in a straight path. A light ray is an arrow that represents the path and direction of a wave. A light wave has a flat leading edge called a wave front. The light ray (path) is normal (90°) to the wave front.

AMOUNT OF ENERGY IN PHOTON

The amount of energy (E) in a photon increases with frequency (f) and can be calculated using Planck's constant (h).

$E = h \times f$ (Watts) = 6.63×10^{-34} (Joule-seconds) $\times$ f (Hz)

A photon of red light having a wavelength of 650 nm and frequency of 461.5 THz (1THz = 10^{12}Hz), contains about 3×10^{-19}Watts (0.0000003pW) of energy. Infra-Red light at 319 THz possesses even less energy than red light.

LIGHT POWER

Light power is defined several different ways under different circumstances. Optical power, which includes all light types, is specified using Radiometric parameters. For visible light, Photometric parameters can be used to indicate the visibility of light in the range of wavelengths that we can see.

RADIOMETRIC PARAMETERS

Five radiometric parameters are used to specify power from a light source (Emitter):

- **Radiant Energy -** The total energy emitted from a source.
- **Radiant Power (Flux) -** The total power (time rate of energy flow) emitted from a source.
- **Radiant Intensity -** The power emitted from a source per unit solid angle.
- **Radiant Emittance -** The power emitted from a source per unit surface area.
- **Radiance -** The intensity emitted from a source per unit surface area.

PHOTOMETRIC PARAMETERS

Five Photometric parameters are used to specify power from a visible Light Source or Emitter:

- **Luminous Energy** - The total energy emitted from a visible source.
- **Luminous Power (Flux)** - The total power (time rate of energy flow) emitted from a visible source.
- **Luminous Intensity (Light intensity)** - The power emitted from a visible source per unit solid angle.
- **Luminous Emittance (Light density)** - The power emitted from a visible source per unit surface area.
- **Luminance** - The intensity emitted from a visible source per unit surface area.

Radiometric and photometric parameters are specified with many different units of measure. Some of these units, lumens for example, are used strictly for photometric, not radiometric. A common unit for radiant Emittance measure is mW/cm^2

REFLECTION

One of the most familiar properties of light is its ability to be reflected. When a ray of light is reflected by a smooth and flat surface, the incident ray angle and the reflected ray angle, as shown in Fig. 2.5-3, are equal. Reflection also occurs from surfaces, which are not smooth or polished.

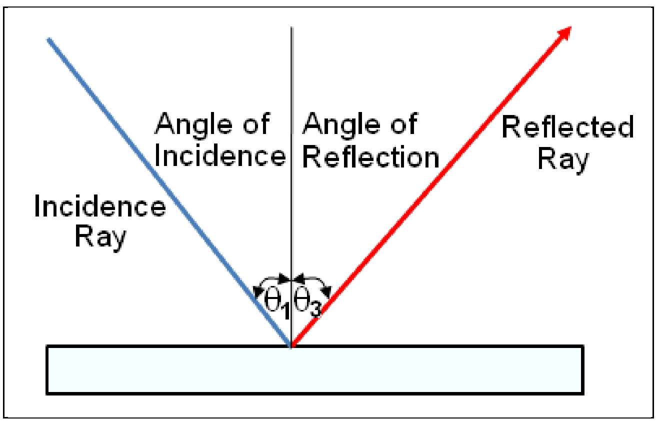


Fig. 2.5-3 Reflection

The direction of travel of a reflected light beam depends on the roughness of the reflecting surface relative to the wavelength of the reflected light. If the wave is incident on a rough surface, the reflected wave travels in many directions, as shown in Fig. 2.5-4. Reflection in many directions is called Diffused Reflection and occurs if the irregularities in the reflecting surface are about the same size or are larger than the wavelength of the light wave striking the surface.

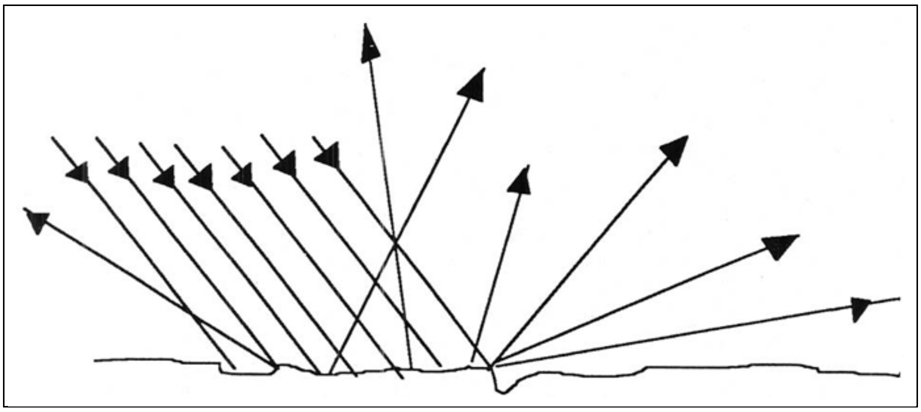


Fig. 2.5-4 Diffuse Reflection

REFRACTION

A second major property of light is its ability to be refracted. The light rays are refracted (or bent) at the interface between the two media. The wave front turns, which changes it direction and bends its path (ray)? The bending of light as it moves between materials is called *Refraction*. Refraction results from light traveling at different speeds in different media, such as air, water, glass and other transparent substances. When light passes from air into water, it is abruptly slowed down from a velocity of about 186,000 miles per second to about 140,000 miles per second. If a ray strikes the surface of a denser substance at any angle other than 90°, it will travel through that substance in a different direction, closer to the normal. This phenomenon is shown in Fig. 2.5-5. The new direction is determined by the Index of Refraction of the substance. The Index of Refraction is the ratio of the velocity of light in a vacuum (c = 300,000 km/s) to the velocity of light in that substance (v). Light traveling in a vacuum has a constant velocity of 300,000 km/s. Light travels through glass has a

velocity of 200,000 km/s. In the example above, the glass has an Index of Refraction of 1.5. The Index of Refraction of air is approximately 1. Thus, the speed of light in air is only slightly slower than that of light in a vacuum. The refractive indexes of some other common substances are water, 1.33; glass 1.51. Clearly light travels slower in glass than in a vacuum or in air. The Approach Angle of the light ray is called the Angle of Incidence (θ_1).

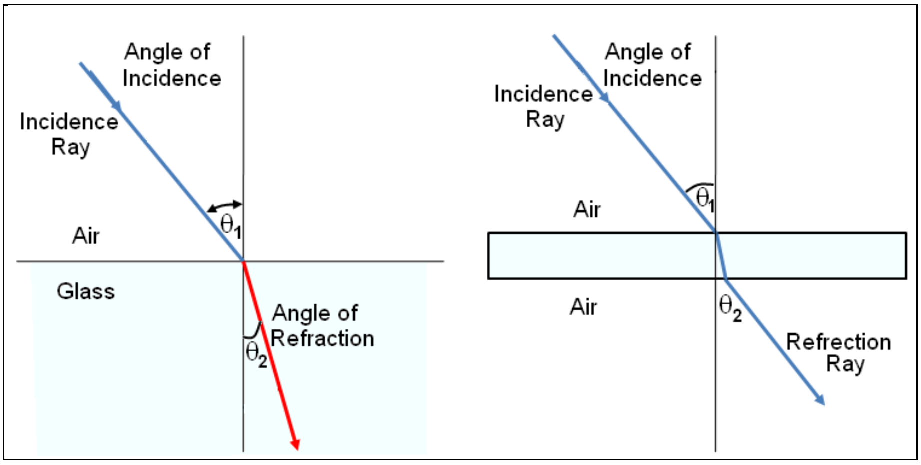


Fig. 2.5-5 Refraction

The Incident Angle of the light is measured between the light ray and a line 90° (normal) to the change in Index of Refraction. The Index of Refraction of the first material is η_1, the Angle of Refraction is θ_2, and the Index of Refraction of the second material is η_2, as shown in Fig. 2.5-6.

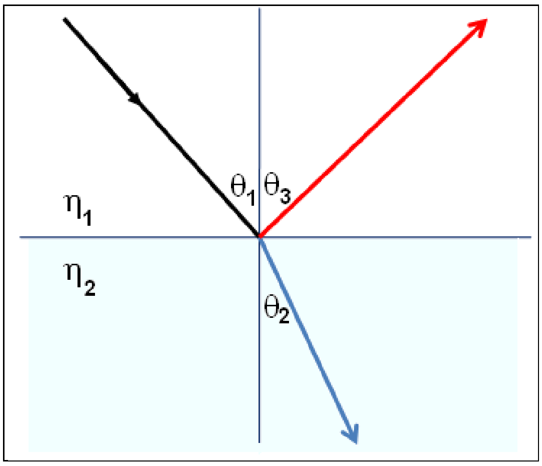


Fig. 2.5-6 Angle of Incidence versus Angle of Refraction

SNELL'S LAW

Snell's law gives the relationship between the Angle of Incidence and the Angle of Refraction.

$$\eta_1 \sin(\theta_1) = \eta_2 \sin(\theta_2)$$

Whenever light travels through a change in index (η_1 to η_2), a portion of light is always reflected back into the first material. This reflection is called Fresnel reflection.

EXAMPLE 2.5-1

If η_1 for glass is 1.5, η_2 for air is 1 and the Incident Angle (θ_1) is 28°. Using Snell's law, calculate the Angle of Refraction (θ_2). $\eta_1 \sin(\theta_1) = \eta_2 \sin(\theta_2)$

SOLUTION

$$1.5 \times \sin(28^o) = 1 \times \sin(\theta_2)$$

$$\sin\theta_2 = 1.5 \times \sin(28^o)$$

$$= 1.5 \times (0.4695) = 0.7042$$

$$\theta_2 = \sin^{-1}(0.7042) = 44.77^o \approx 45^o$$

EXAMPLE 2.5-2

If η_1 for glass is 1.5, η_2 for air is 1 and the Incident Angle (θ_1) is 42°. Using Snell's law, calculate the Angle of Refraction (θ_2). $\eta_1 \sin(\theta_1) = \eta_2 \sin(\theta_2)$

SOLUTION

$$1.5 \times \sin(42^o) = 1 \times \sin(\theta_2)$$

$$\sin\theta_2 = 1.5 \times \sin(42^o)$$

$$= 1.5 \times (0.669) = 1$$

$$\theta_2 = \sin^{-1}(1.0) = 90^o$$

As shown in Fig. 2.5-7, increasing the incident angle (θ_1) to 42° causes the Angle of Refraction (θ_2) to increase to 90°, where all light still remains in the glass. Total reflection occurs when the incident angle (θ_1) is greater than the Critical Angle (θ_C). The Critical Angle (θ_C) equals the Incident Angle (θ_1), which causes Angle of Refraction (θ_2) to be 90° so that both sides of Snell's equation are equal to 1:

$$\eta_1 \sin(\theta_1) = \eta_2 \sin(\theta_2)$$
$$1.5 \times \sin(42) \approx 1 \times \sin(90) \approx 1$$

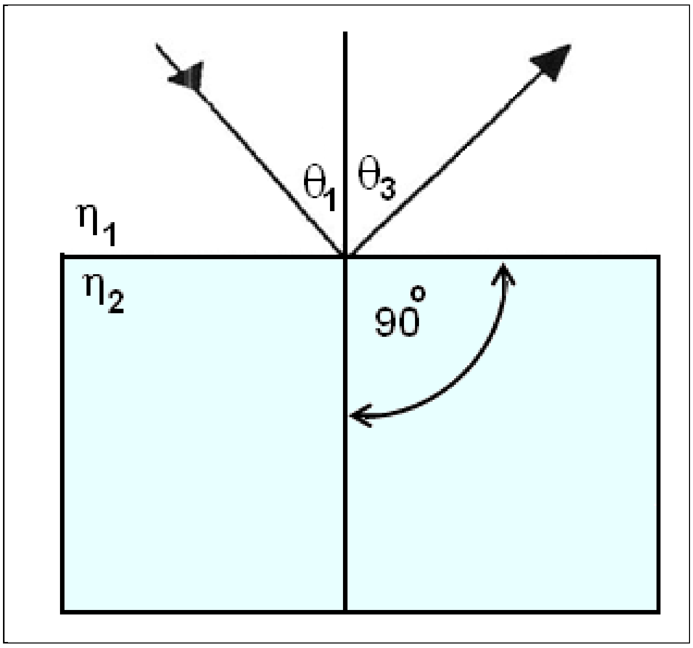


Fig. 2.5-7 Critical Angle

As shown in Fig. 2.5-7, consider a ray that has an Incident Angle greater than the Critical Angle at the glass to air, the light is totally reflected at an angle (θ_3), which equals the Incident Angle. The glass top and bottom surface are parallel, forming a rectangle between the glass boundaries and the normal lines. The reflections repeat as the light ray propagates within the glass, as shown in Fig. 2.5-8.

Table 2.5-1 shows Index of Refraction versus speed of light in different transmission mediums.

MATERIAL	η	v (miles/sec)
Air	1	186,000
Diamond	2.42	77,000
Glass	1.5-1.9	124,000-98,000
Water	1.33	140,000
Optical Fiber	1.5	124,000

Table 2.5-1 Index of Refraction (η) versus Speed of Light (v)

DISPERSION

The process of separating light according to its frequency is called Dispersion. A prism, for example, disperses white light by refraction, causing the different wavelengths (or colors) to travel in different directions, thus separating them and forming a spectrum, as shown in Fig. 2.5-8.

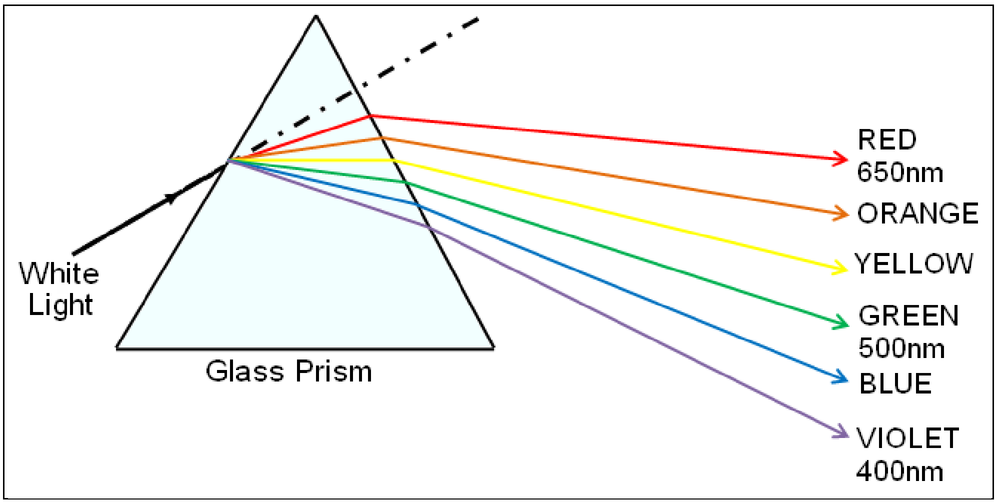


Fig. 2.5-8 Dispersion

LIGHT ABSORPTION AND SCATTERING

Absorption is a phenomenon whereby light strikes a substance and gives up some or all of its energy to the atoms of that substance. If the atoms retain the energy, it is converted to heat. In some substances, the light energy given to the atoms of the substance raises their energy level to the point where they, in turn, emit light. If this

light is emitted as light of a longer wavelength, the process is called Luminescence. If the light energy is emitted as light at the same frequency as the incident light, the light is said to be scattered. Scattering is spreading rays in all directions and light diffusion is the scattering.

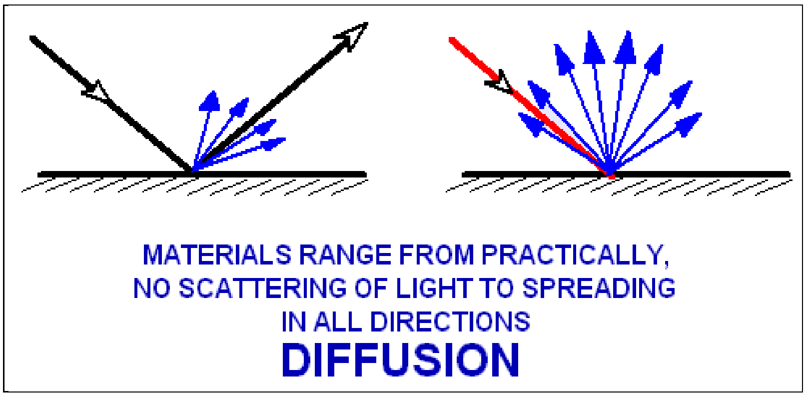


Fig. 2.5-9 Radiant Scattering

Regarding the propagation of light energy, either in air or in some other transparent material, we recognize that there is some loss or attenuation of light energy. This attenuation is largely due to absorption and/or scattering as the light waves propagate through the medium.

BASIC OPTICAL MECHANISM

Fig. 2.5-10 shows a light source (flashlight) positioned to illuminate the end of a section of pipe. Note that some of the light rays will not be coupled into the pipe at all. Under these conditions, less light wave energy is available at the distant end of the pipe for detection.

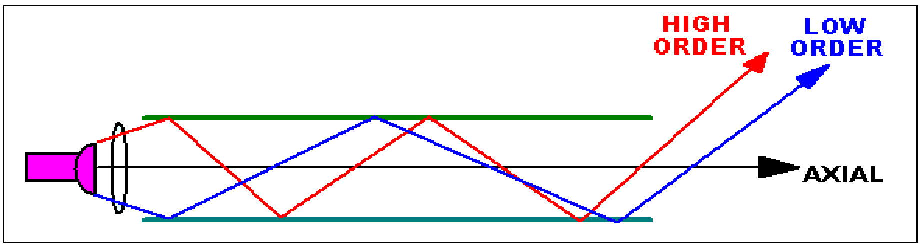


Fig. 2.5-10 Reflective Propagation

If a lens has been positioned between the light source and the pipe, which focuses the light beam more narrowly, so that more light energy is coupled into the pipe and thus more energy will be available for detection at the distant end. Quite clearly, any light source that inherently emits a narrower beam of light will couple into a light guide (pipe) more efficiently. The light gathering capability of the light guide will be useful when referred to the “degree of openness” or the “Cone of Acceptance” that the end of the pipe presents to the incident light.

ACCEPTANCE ANGLE

Acceptance Angle, as shown in Fig. 2.5-11, is the angle between light and the fiber axis at which half reduce the fiber power output where the Acceptance Angle is 27.5°.

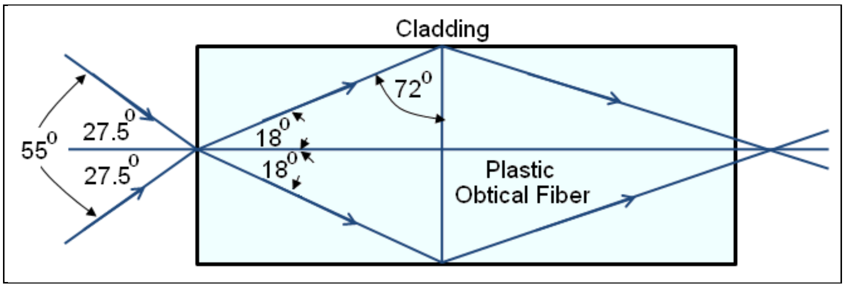


Fig. 2.5-11 Acceptance Angle/Acceptance cone

The Angle of Refraction at the air to the core boundary must be 18°. The light rays encounter the cladding at angles greater than the critical angle (72°), reflect off the cladding, and propagate in the fiber core.

ACCEPTANCE CONE

As shown in Fig. 2.5-12, a three dimensional representation of light acceptance defined by rotating the fiber Acceptance Angle around the fiber axis. The Acceptance Cone is the cone of light that will be totally internally reflected down the core of the fiber. Any rays entering the fiber from outside this cone will refract into the cladding. These rays of light will be scattered, absorbed, refracted, or reflected. Some will go

into the cladding; others will reflect off of the outer wall of the cladding and back into the core to the cladding on the other side of the fiber. These are called Cladding Pathways and can cause measurements of light passing through the core to appear higher that what they truly are.

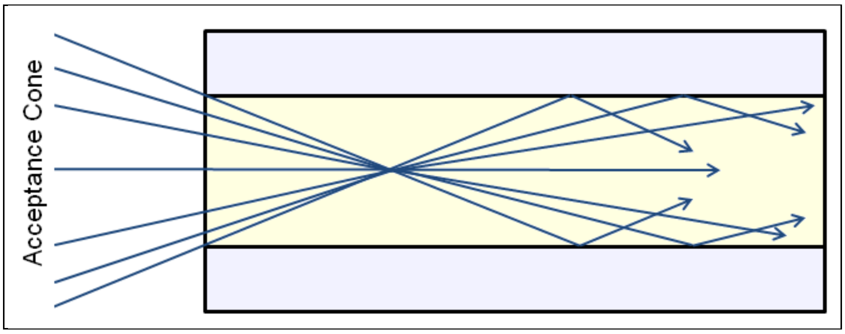


Fig. 2.5-12 Cone of Acceptance

NUMERICAL APERTURE (NA)

In optics, the numerical aperture (NA) of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light such that the NA of a beam is constant as the beam goes from one material to another provided there is no optical power at the interface. The exact definition of the term varies slightly between different areas of optics. The numerical aperture with respect to a point P depends on the half-angle θ of the maximum cone of light that can enter or exit the lens.

$$NA = n\ \sin\theta$$

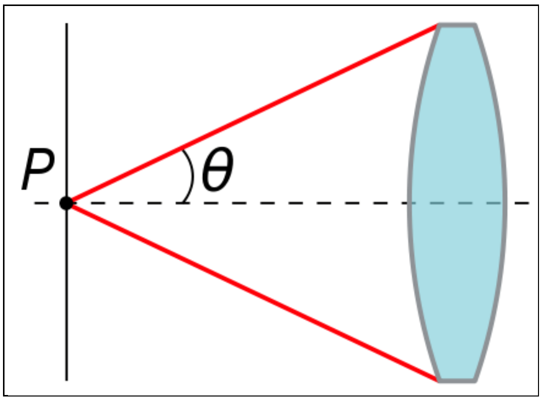


Fig. 2.5-13 Numerical aperture of a thin lens

COMPARISON OF ELECTRICAL AND FIBER OPTIC TERMS

It is important to understand some basic terms used in Fiber Optic technology compared with those in the electrical field, as shown in Table 2.5-2 below.

ELECTRICAL	FIBER OPTIC
Electrons	Photons
Power	Flux
Voltage Drop	Flux budgeting
Circuit	Link
Conductor	Core/Cladding
Stranding	Bundling
Current rating	Numerical Aperture
Impedance/Transmission Loss	Attenuation/Dispersion

Table 2.5-2 Common Terms

SUMMARY

- The unit of light is photon.
- When light is absorbed by a material or substance, the photon ceases to exist.
- The photon energy is converted to some other form of energy, such as heat.
- Since light is electromagnetic energy that travels in a wave front like sound or radio waves, light can be identified within the general electromagnetic spectrum.
- At light wave frequencies, it is convenient to use wavelength instead of frequency.
- At such frequencies, the wavelengths are very short and are usually denoted in nanometers (nm), a unit of length denoting one billionth (10^{-9}) of a meter.
- Some of the properties of light are its ability to be reflected, diffused, refracted, dispersed, diffracted, absorbed, and scattered.
- Any source of light wave energy can couple light energy into an optical fiber.

- A source emitting a narrower beam of light will couple more energy into a fiber than a source with a widely diverging beam.
- Light may propagate directly, reflectively or refractivity through a fiber.
- Wavelength (λ) is the distance an electromagnetic (light) wave travels during one cycle.
- Light wavelength is calculated by dividing the velocity of light in a vacuum (300,000 km) by the light frequency. The range of wavelength in the visible light spectrum is 770-390 nm.
- Light that remains in the air outruns the slower light in the glass. The wave front turns, this changes its direction and bends its path (ray). The bending of light as it moves between materials is called Refraction.
- Light traveling through glass has a velocity of 200,000 km.
- Index of Refraction is the ratio between light velocity in a vacuum (c = 300,000 km/s) and light velocity in a material (v).
- The glass has an Index of Refraction of 1.5.
- A light wave moves away from its source in a straight path. A light ray is an arrow that represents the path and direction of a wave.
- The light Approach Angle can cause part of the wave front to enter glass while the remainder is still in the air.
- The Approach Angle of the light ray is called the Angle of Incidence (θ_1). The Incident Angle of light is measured between the light ray and a line 90° (normal) to the change in Index of Refraction.
- The Angle of Refraction is also measured between the light ray and a line normal to the change in Index of Refraction.
- Snell's law gives the relationship between the Angle of Incidence and the Angle of Refraction.
- The glass is acting as a waveguide, steering the light using total reflection at the glass-to-air boundaries.
- The term "Numerical Aperture" (NA) defines the Acceptance Cone of a fiber or a terminal optical device, such as a Photo Detector.

GLOSSARY

Absorption: Power loss from the conversion of light energy to heat.

Acceptance Angle: The angle between light and the fiber axis at which the fiber power output is reduced by half.

Acceptance Cone: A three dimensional representation of light acceptance defined by rotating the fiber Acceptance Angle around the fiber axis.

Angle of Incidence: The Approach Angle of a light ray between a light in the first material to a line normal to the change in Index of Refraction.

Angle of Refraction: The angle between a light rays in the second material to a line normal to the change in Index of Refraction.

Cladding: A coating surrounding the optical fiber core that has a lower Index of Refraction.

Critical Angle: The largest Angle of Incidence permitting the refraction of light, beyond which all the light rays will be reflected through the fiber optic

Dispersion: The spreading of energy in time.

Electromagnetic Spectrum: The range of electromagnetic wavelengths where radiant energy oscillates between electric and magnetic fields.

Fresnel Reflections: A portion of light that is always reflected off a change in Refractive Index.

NA: Numerical Aperture, it represents an optical fiber's Acceptance Angle.

Scattering: Misdirecting or spreading of light power.

Waveguide: Boundaries that direct electromagnetic energy.

Laser: Light Amplification by stimulated Emission of Radiation.

Photometric: A system or parameter used to specify visible properties of electromagnetic radiation.

Photon: Elementary quantity of radiant energy, considered as particle of light.

Radiation: The emission of electromagnetic energy.

Radiation Efficiency: Ratio of radiant power to input power of a light source.

Radiometric: A system or parameter used to specify physical properties of electromagnetic radiation.

FORMULAE

10A = 1nm = 10^{-9} m

E = h x f (Watts) = 6.63 x 10^{-34} (Joule-seconds) × f (Hz)

Snell's Law

η1 sine (θ1) = η2 sine (θ2)

where η1 = Index of Refraction, medium 1

η1 = Index of Refraction, medium 2

θ1 = Angle of Incidence, medium 1

θ2 = Angle of Refraction, medium 2

NA = Sine (θ1) where NA = Numerical Aperture

θ1 = Angle of Incidence, medium 1

REVIEW EXERCISE

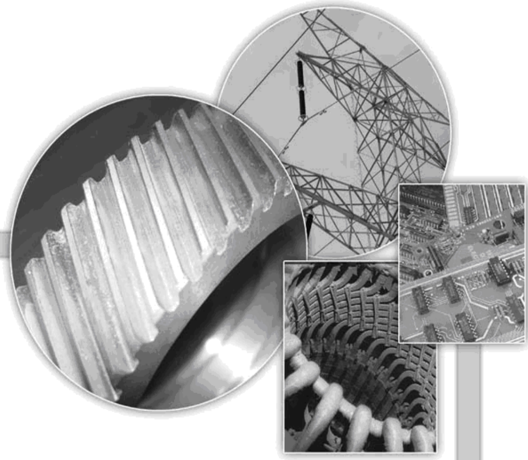
Answer True or False	T	F
1. Light can be completely and satisfactorily explained as a system of particles.		
2. A photon has measurable mass.		
3. A photon has a measurable level of energy when it is at rest.		
4. The wavelength of an alternating wave is the distance it travels in one half a cycle.		
5. We can state the wavelength of a signal in units of measure of length without regard to the medium that the wave is propagating in.		
6. A light wave of a given frequency will travel at the same speed in any medium.		
7. Different light wave frequencies will travel at the same speed within the same medium.		
8. A light wave signal with a wavelength of 800nm would be a higher frequency signal than a different signal with a wavelength of 1300nm.		
9. Light is a form of energy and, as such, can be converted to other forms of energy.		
10. When light impinges on certain materials, those materials give off electrons.		
11. When impinging light is reflected by a smooth surface, the Angle of Incidence is twice the value of the Angle of Reflection.		
12. The efficiency of transfer of light energy between two fiber ends depends upon the Numerical Apertures of both fibers.		
13. When light passes from a less dense medium into a denser medium, the velocity of transmission decreases.		

14. The NA of a fiber denotes the maximum angle of light entering the end of the fiber that will be propagated within the core of the fiber.		
15. Smaller NA makes it more difficult to couple light energy into the fiber.		

16. If the incident angle of light is 45° at the air to glass, the Angle of Refraction is ______:
    a) 0.47
    b) 28°
    c) 30°
    d) 45°

17. What is the Critical Angle for glass to air boundary?
    a) 41.8
    b) 40
    c) 0.012
    d) None of above

18. Which is not a radiometric measure of power?
    a) W (watt)
    b) Lm/W (Lumens per watt)
    c) μW/sr (micro-Watts per Steradian)
    d) mW/cm^2 (milli-Watts per square centimeter)



LESSON 2.6

FIBER OPTIC COMMUNICATIONS

LESSON 2.6
FIBER OPTIC COMMUNICATIONS

OVERVIEW

This lesson identifies the components of the Fiber Optic Communication system and explains the function and operation of optical transmitter, driver circuit and fiber optic receiver concluding with the source-to-fiber connection and repeaters.

OBJECTIVES

Upon completion of this lesson, the trainee should be able to:

- List the components of the Fiber Optic Communication System.
- State the function of optical transmitter.
- State the function of the driver circuit.
- State the function of the fiber optic receivers.
- Explain the function of source-to-fiber connection and repeaters.

INTRODUCTION

Before we go into the specific details of fiber optics, it is important that you grasp a clear picture of the overall fiber optic system. Seeing the big picture will help, you put individual pieces in the right perspective. The fiber optic system consists primarily of a light source and transmitter at the sending end. The optical light source converts the electrical signal into optical signal and may be a semiconductor laser or Light Emitting Diode (LED), a waveguide carrier and a receiver.

Fig. 2.6-1 shows the principal components of a general fiber optic communication system. The Transmit terminal equipment consists of an information encoder or signal shaping circuit preceding a modulation or electronic driver stage, which operates the optical source. Light emitted from the source is launched into an optical fiber incorporated within a cable, which constitutes the transmission medium. The light emerging from the far end of the transmission medium is converted back into a transmission signal by an optical detector positioned at the input of the Receive terminal equipment. This electrical signal is then amplified prior to decoding or demodulation in order to obtain the information originally transmitted.

Beginning at the upper left of Fig. 2.6-1, we have a source of analog information, which may be a telephone user. The analog signal is converted into a sequence of binary digits using an Encoder. The binary data stream emitted by the coder can be converted back into an analog signal by a Decoder. A digital transmission system is used to transport the binary data from the Coder output to the Decoder input.

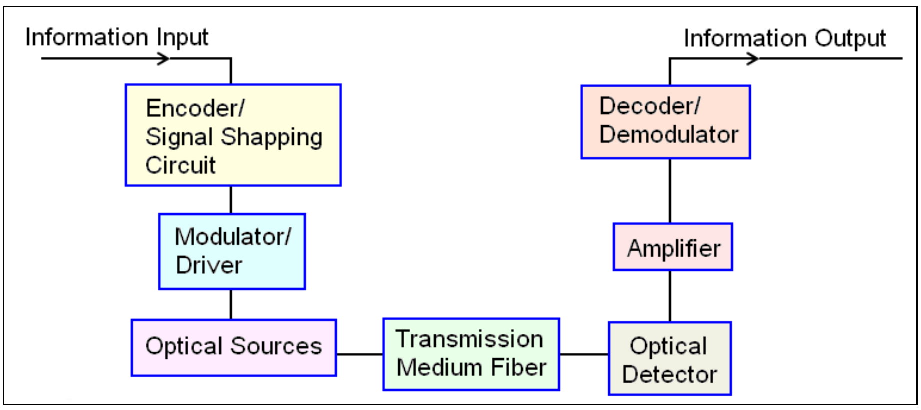


Fig. 2.6-1 Fiber Optic Communication System Components

One needs an optical transmitter, a fiber, and an optical receiver to implement the transmission function with optical fibers as shown in Fig. 2.6-2.

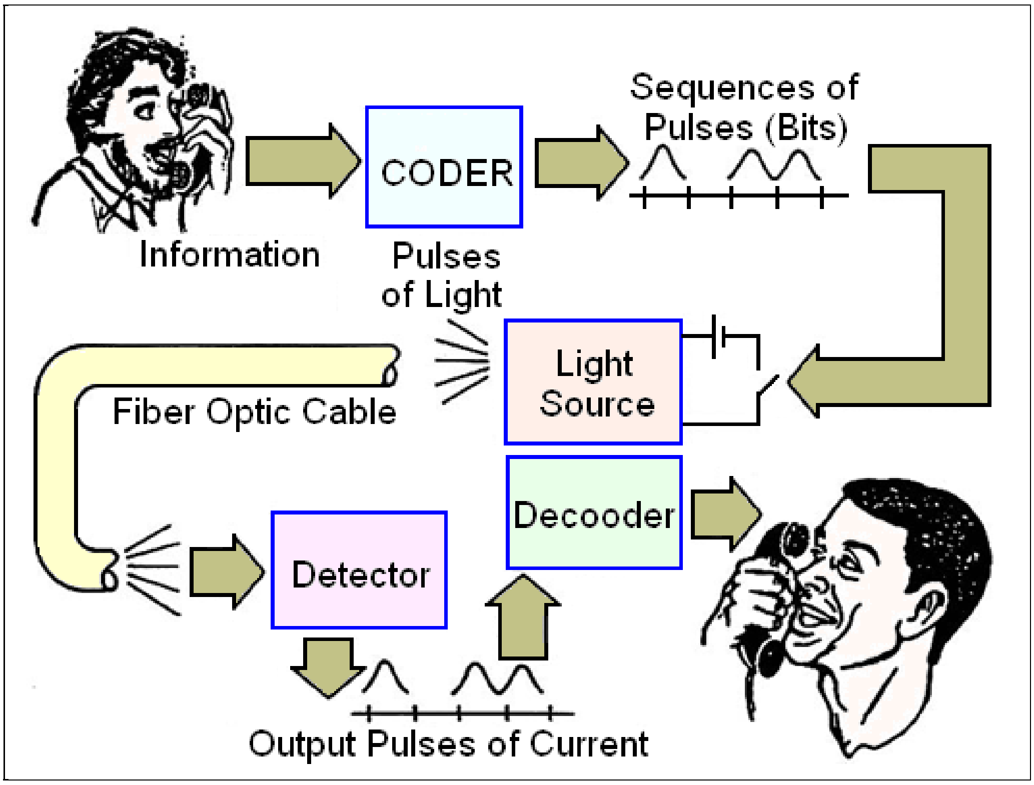


Fig. 2.6-2 Functional Components Communication System

FIBER OPTIC TRANSMITTER

The optical transmitter converts electrical pulses into pulses of optical Power as shown in Fig. 2.6-2. The fiber captures some fraction of the power emitted by the transmitter and transports it to the receiving end of the link. A light source in a fiber optic transmitter converts electrical energy to radiant electromagnetic energy that may be either visible or invisible. The two major types of light sources used in transmitters are Light Emitting Diode (LED) and laser. LEDs are made in two forms, edge emitting, and surface emitting.

Semiconductor lasers are similar in construction to edge-emitting LEDs. Emitted light from each laser is relatively compact and focused, thereby producing a coherent narrow beam. The laser's narrower spectral width makes it useful for longer distances and wider bandwidths.

Both light sources emit light in one of three different wavelengths, 850μm, 1300μm, and 1500μm. These are low loss in which the glass fiber can carry light with minimum attenuation. All three wavelengths are in the Infra-Red (IR) portion of the electromagnetic spectrum. The velocity of light through glass varies with frequency. The must launch enough optical power into a fiber optic to overcome losses inherent in the core, somewhat similar to electrical conductor losses, so that sufficient power is delivered to the receiver to produce a clear signal. Light energy is attenuated due to scattering in the fiber, absorption into or through the cladding, as well as the inherent loss of light at each fiber splice. The term decibel (dB) is used to describe the value of this total power loss.

DRIVER CIRCUIT

A fiber optic transmitter requires electronic circuitry, called the Driver Circuit, to control the electrical input to its light source to give modulation of the light wave carrier, as shown in Fig. 2.6-3.

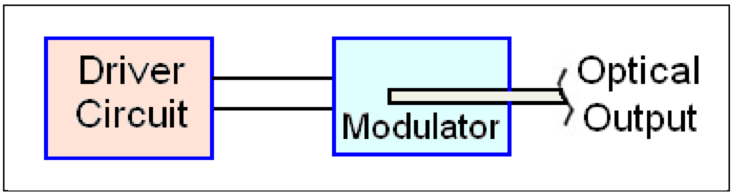


Fig. 2.6-3 Driver Circuit

The laser driver circuit directly modulates the intensity of the semiconductor laser with the encoded digital signal. Hence, a digital optical signal is launched into fiber optic cables. A driver circuit, without overheating, must apply electrical power to a light source so that enough optical power is produced for the system.

TRANSMISSION MEDIUM

The Transmission Mediums consist of fiber optic cable, a pair of wires, and a coaxial cable through which the signal is transmitted to the receiver, where it is transformed

into the original electrical information signal (demodulated) before being used at the receiver end. The signal is attenuated through the transmission medium or suffers loss and is subjected to degradation due to random signals and noise or splicing. An optical fiber is fragile; therefore, it must be protected against mechanical forces (both compression and tension) along with dirt and moisture, which can degrade the light-carrying capability.

SOURCE-TO-FIBER CONNECTION

The source-to-fiber connection in a fiber optic transmitter is an optical and mechanical interface between the light source (LED or laser) and one end of the optical fiber. The light source and fiber optic must be properly aligned to minimize losses.

FIBER OPTIC CABLE CONSTRUCTION

Fig. 2.6-4 shows the construction of fiber optic cables. The primary coating is considered to be a part of the fiber, not the cable and provides protection, strength, and flexibility for the fiber. Colors are added in order to provide identification for installation and repair of the cable. The reason for coloring is that there is usually more than one fiber in the buffer tube. The first level of protection for fiber optic is a buffer tube with either a loose tube or a tight tube design.

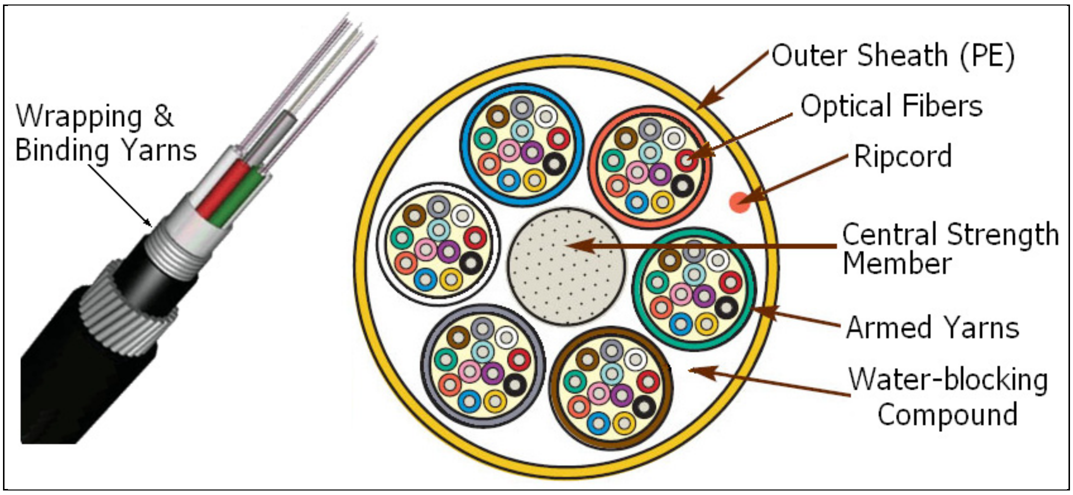


Fig. 2.6-4 Fiber Optic Cable Construction

FIBER OPTIC RECEIVER

A fiber optic receiver consists of a light detector, fiber-to-detector connection and an output circuit. The fiber-to-detector connection allows light from the fiber to illuminate the light detector. The light detector converts an optical signal delivered by the fiber optic to an electric current signal. The output circuit converts the light detector signal into a format compatible with other system components. To receive the light, we use one of two possible detectors, either a Positive Intrinsic Negative Photodiode (PIN) or Avalanche Photodiode (APD), as shown in Fig. 2.6-5.

Standard (PN) photodiodes respond too slowly for telecommunications. Therefore, PIN diodes are better designed as fiber optic detectors. PIN layers are designed with P-type and N-type materials with a thin layer of I-type in between them.

APDs are used when power is major consideration, such as when using lasers and single mode systems.

Fig. 2.6-5 Photo Detector Devices

REPEATERS

The transmission of optical signals over long distances requires regeneration of the signal because of the signal distortion and attenuation. Thus, stations to receive regenerate, and retransmit the signal are established along the long haul lines and are

called Repeater or Regeneration Stations. From a practical point of view, a long haul fiber optic system consists of many small systems made up of transmitters, channels, and receivers. For, each Repeater requires a transmitter and receiver for each fiber to lower the attenuation in fibers and increase the power of the transmitters. For example, a typical length between Repeaters with a 1300μm system is 26km.

SUMMARY

- The combination of optical and electronic technology used in the transmitter takes electrical signals and converts them into light pulses. The receiver reverses the process, taking the weaker light pulses and converting them back into electrical signals and amplifying them.
- The two major types of light sources used in transmitters are light emitting diodes (LED) and lasers.
- LEDs are made in two forms, edge emitting, and surface emitting. These terms refer to the location on the chip from which the light is emitted.
- Surface emitters are similar to LED panel indicators that radiate light in a relatively wide beam. Edge emitters have a smaller, more focused beam.
- LEDs have high reliability and are used for transmitting relatively short distances.
- Semiconductor lasers are similar in construction to edge-emitting LEDs. Emitted light from each laser is relatively compact and focused, thereby producing a coherent narrow beam. The laser's narrower spectral width makes it useful for longer distances and wider bandwidths.
- The light-generating transmitter must launch enough optical power into fiber optic to overcome losses inherent in the core, somewhat similar to electrical conductor losses, so that sufficient power is delivered to the receiver to produce a clear signal.
- Light energy is lost (attenuated) due to scattering in the fiber, absorption into or through the cladding caused by micro bending, as well as the inherent loss of

light at each fiber splice. The term decibel (dB) is used to describe the value of this total power loss.

- The transmission of optical signals over long distances requires Repeaters to compensate for the signal distortion and attenuation.

GLOSSARY

LED: Light Emitting Diode, PN junction semiconductor device that emits coherent optical radiation when biased in the forward direction.

IR: Infra Red.

PIN: Positive Intrinsic Negative Photodiode.

APD: Avalanche Photodiode.

DB: Decibel.

Laser: Acronym for “light amplification by stimulated emission of radiation.” A device, which generates or amplifies electromagnetic oscillations at wavelengths between the far Infrared and Ultra-Violet.

Light Source: A generic term that includes lasers and LEDs.

Optical Detector: A transducer that generates an output signal when irradiated with optical power.

PIN Photodiode: A diode with a large intrinsic region sandwiched between P-doped and N-doped semiconducting regions. Photons absorbed in this region create electron-hole pairs that are then separated by an electric field, thus generating an electric current in a load circuit.

REVIEW EXERCISE

1. The two power levels in fiber optics are compared in _____.
   a) Decibels (dB)
   b) Watt
   c) Volt Ampere
   d) None of the above

2. The fiber optic receiver (FOR) on the fiber optic communications circuit board ______________________.
   a) uses a PIN photodiode
   b) converts electric current to voltage
   c) uses a standard PN photodiode
   d) None of above

3. Emitted light from a laser is relatively ________________________.
   a) compact
   b) focused
   c) producing a coherent narrow beam
   d) all of the above

4. Light energy is attenuated due to ______________________.
   a) scattering in the fiber
   b) absorption into or through the cladding
   c) the loss at each fiber splice
   d) all of the above

5. The fiber optic system consists primarily of a __________________ at the sending end.

6. The transmit terminal equipment consists of ________________________ _________________________________, which operates the optical source.

7. The light emerging from the far end of the transmission medium is converted back to a transmission signal by ___________________________________ ________________________.

8. The analog signal is converted into a sequence of binary digits using an ___________________.

9. The binary data stream emitted by the coder can be converted into an analog signal by _________________.

10. A light source in a fiber optic transmitter converts _____________ energy into ___________ energy that may be either visible or invisible.

11. The two major types of light sources used in transmitters are _____________ and ______________.

12. The driver circuit is used in the transmitter to __________________________.

13. Colors are added to fiber optic cables in order to __________________.

14. The first level of protection for a fiber optic is a ________________________ __________________________.

15. A fiber optic receiver consists of _________________________________ _____________________.

16. The light detector converts an ______________________ delivered by the fiber optic to ______________________.

17. The receiver output circuit converts the _____________ signal into ________.

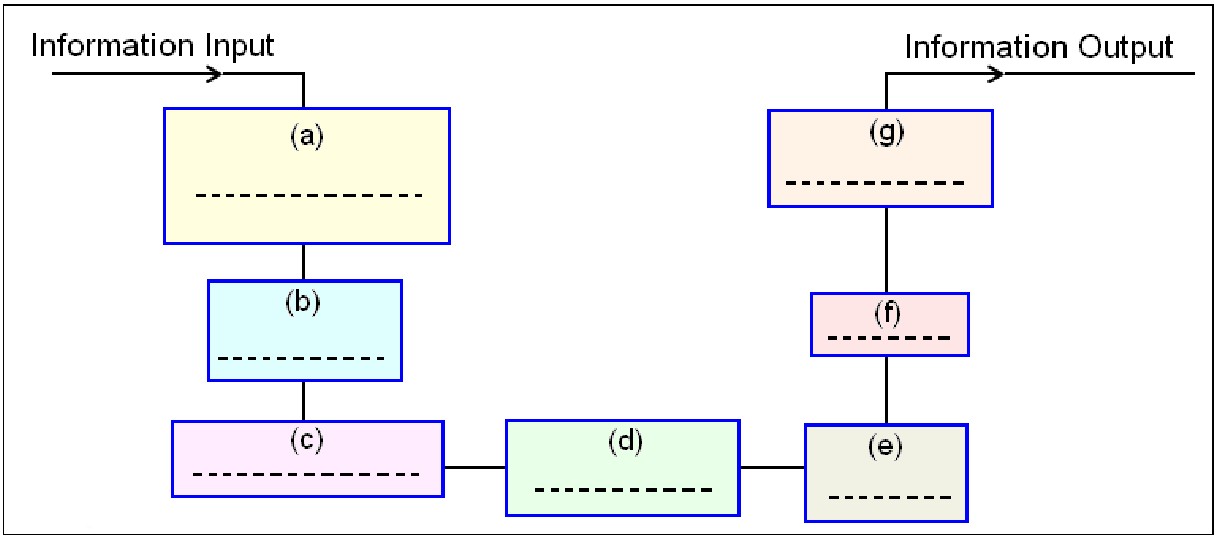
18. The receiver detectors are _________________ or _________________.

19. The transmission of optical signals over long distances requires ______________ of the signal because of the signal __________________.

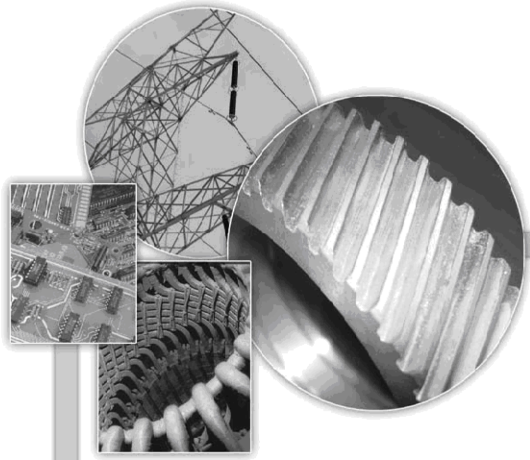
Answer with True or False:	**T**	**F**
20. The laser's narrower spectral width makes it useful for longer distances and wider bandwidths.		
21. Three different wavelengths: 850mn, 1300nm, and 1500nm give low loss in which glass fiber can carry light with minimum attenuation.		
22. Light-generating transmitter must give minimum optical power into an optical fiber to overcome the losses inherent in the core.		

23. Standard PN photodiodes respond too fast for telecommunications.		
24. APDs are used in receivers when less power is needed.		
25. A digital transmission system used to transport the binary data from the coder output to the decoder input.		

26. Match the following items of the fiber optic communication system components with the letters on the diagram shown below:



	Optical Source
	Transmission Medium Fiber
	Amplifier
	Decoder/ Demodulator
	Encoder/ Signal Shaping Circuit
	Optical Detector
	Modulator/ Driver



UNIT 3

NUMERICAL RELAYS

UNIT-1
NUMERICAL RELAYS

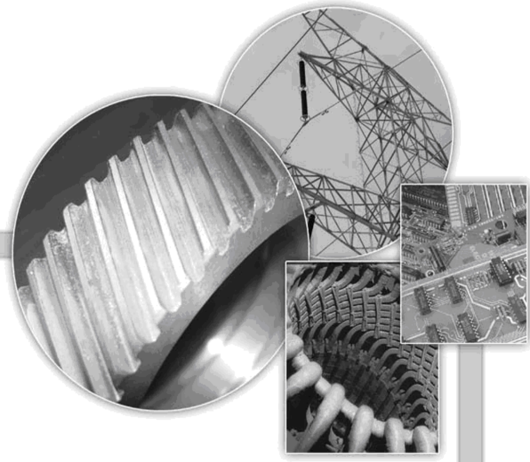
OVERVIEW

This unit discusses the theory and operation of Digital relays, including the main components of the hardware, the microprocessor architects, the flowcharts of the protective schemes, and the digital relay applications.

OBJECTIVES

Upon completion of this unit, the trainee will be able to:

- State the advantages of digital relays.
- List the components and control devices of the hardware.
- Identify the importance of microprocessor.
- Identify the concepts of the software flowcharts.
- Demonstrate and performing the digital relay applications.



LESSON 3.1

HARDWARE STRUCTURE OF DIGITAL RELAYS

LESSON 3.1
HARDWARE STRUCTURE OF DIGITAL RELAYS

OVERVIEW

This lesson discusses the basic elements of hardware structure of digital relay. Including the input and output devices. The lesson scopes out the importance of microprocessor as the relay operator brain and some of the important data conversion processes.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- State the basic structure of digital relay hardware.
- Illustrate the importance of microprocessor in digital relays.
- Describe the interface between I/O ports and microprocessor.
- Verify the conversion system in the digital relay.
- Identify the importance of clock oscillator in the hardware.

INTRODUCTION

The digital protective relays are in general built up from basic hardware used in most complex relay designs, and software, which includes the most instructions and functions of the relay. The hardware of the first generation of digital relays is made from some analog and digital integrated circuits, microprocessors, or microcontrollers. The recent types of relays are made from function blocks arranged in a workspace as a hardware-software package.

Microprocessor-based protective relays often use a few algorithms to manipulate the incoming analog/digital data and operate on it as required by the application, making a decision for the digital relay to trip or not. These algorithms are based on solution of equations, and operations stored through the relay program.

All the data transfer, store, or applying some process are in the digital form like binary, or hexadecimal number form. The recent digital relays are provided with modern communication circuits to talk with the other devices to facilitate getting the required logic and information data or making decisions like tripping or blocking.

BASIC COMPONENTS OF DIGITAL RELY

The digital relay normally includes three fundamental subsystems:

- Signal conditioning subsystem.
- Conversion subsystem.
- Digital processing subsystem.

The first and second subsystems are generally common to all digital protective schemes, while the third varies according to the application of a particular scheme. Each of the three subsystems is built up from a number of components and circuits.

The block diagram shown in Fig 3.1.1 illustrates block diagram hardware of the basic components of digital relay. Note the sequence of the process operation of the system.

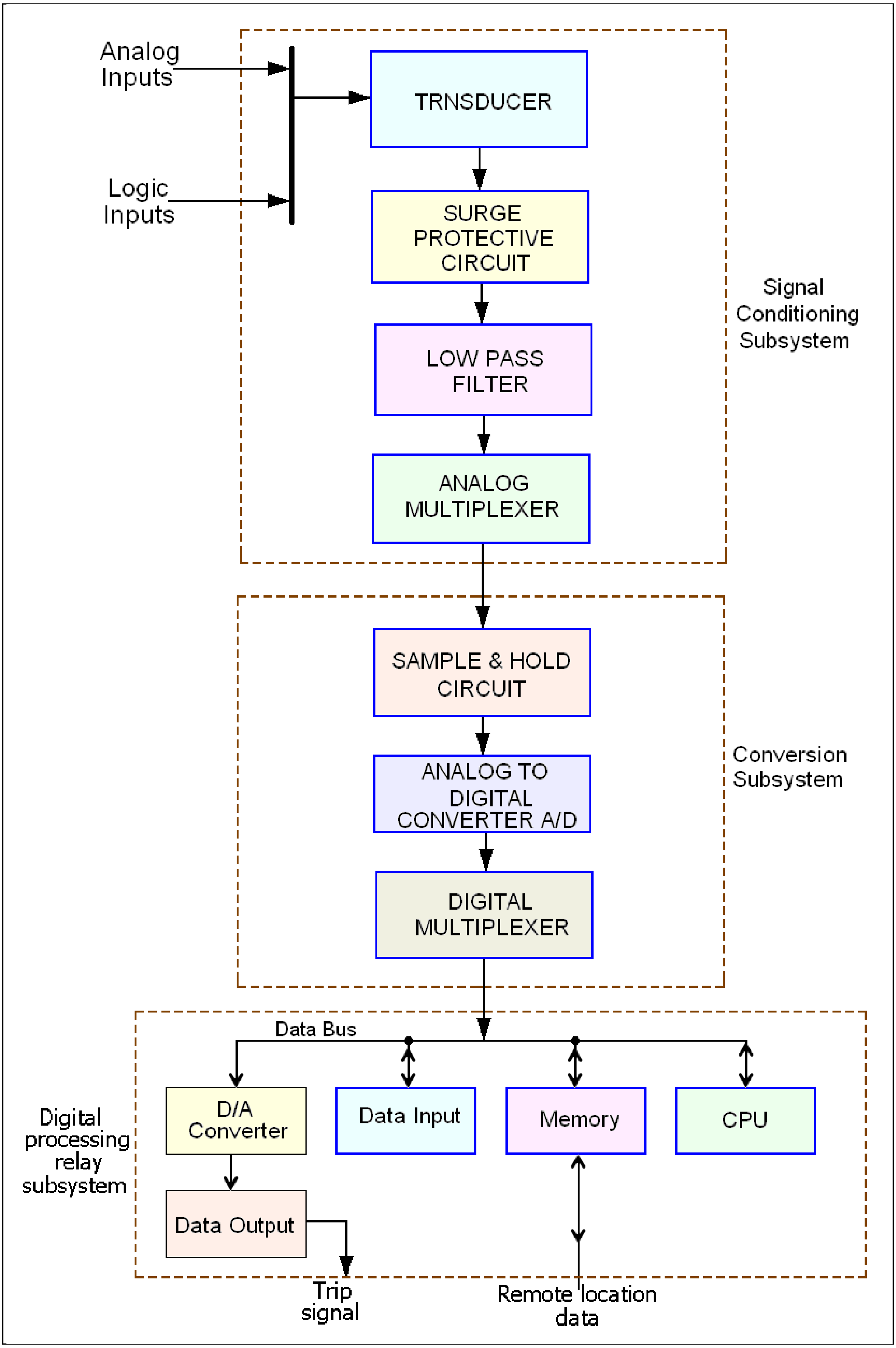


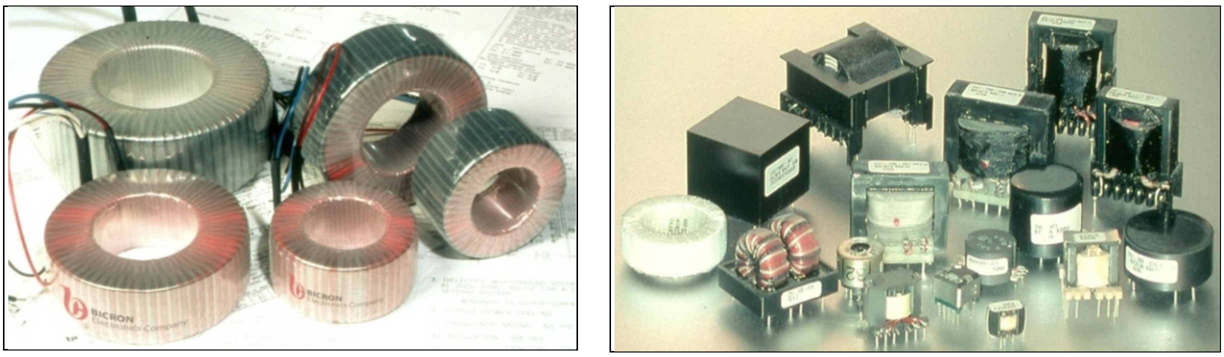
Fig. 3.1-1 Basic components of a digital relay

SIGNAL CONDITIONING SUBSYSTEM

The signal conditioning subsystem receives the input signals, which may be analog (three current phases, three voltage phase or line, neutral current, active power, Var, pressure, and temperature) or logic inputs (circuit breakers and switches position open/close).

TRANSDUCER

It is used to reduce the input signals to much lower level; it receives its inputs from CTs or VTs, since the output of CT is 1A or 5 A, and the VT output is 110V or 120V. The transducer converts these values into milli-amperes or milli-volts, and then feeds those values to the next stage hardware circuits.



(a) Current Transducers (b) Voltage Transducer

Fig. 3.1-2 Transducers used in Digital Relay

SURGE PROTECTIVE CIRCUITS

It includes varistor, Zener diodes, and regulators, isolating transformers or composed of electronic circuit in integrated circuit forms. They are used to protect hardware against voltage spikes due to surges, especially sensitive components such as microprocessors and microcontrollers, which need small voltages to operate.

Fig. 3.1-3 Different Types of Varistor

LOW PASS FILTER

This type of filter is needed to eliminate the unwanted signals such as offset cumulative signal components, which may composed with the main signal due to a problem in the instrument transformers or the transmitting elements. It is used also to correct the input sine waves and helps the relay to recognize it. Low pass filter is discussed in the static relay of the 3A-PSP104 stage. Fig. 3.1-4 shows simple low pass filter circuit and it's characteristic.

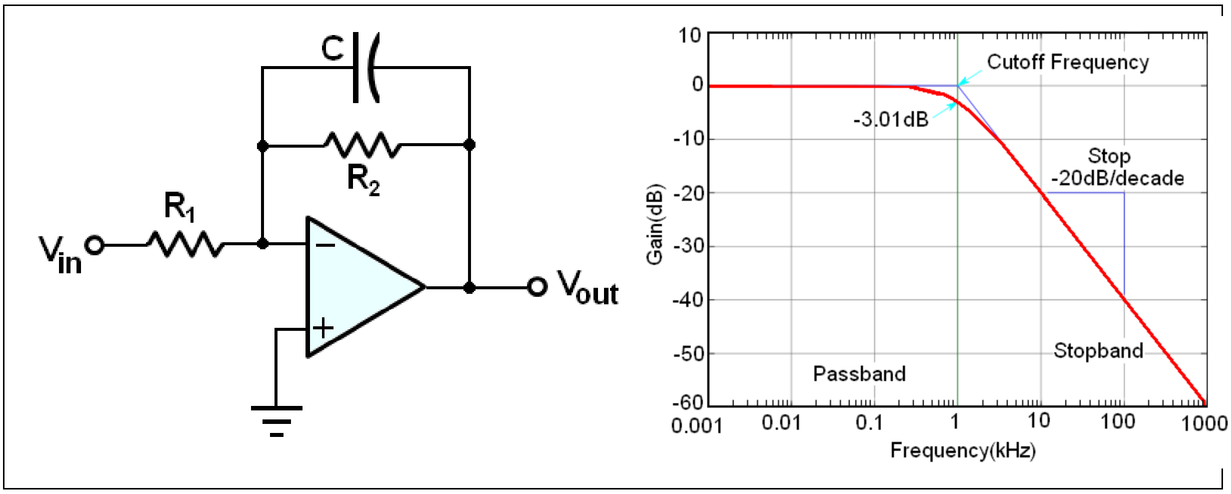


Fig. 3.1-4 Low Pass Filter and it's Characteristic

ANALOG MULTIPLEXER

It is used to select one input signal from number of input channels in sequence and transfers it to the following function block. For example, the digital relay may receive 8-analog inputs, consists of 3-phase currents, 3-phase voltages, neutral current, and logic command. The digital relay can receive and process only one input at a time. Fig. 3.1-5 shows schematic for 8-inputs analog multiplexer.

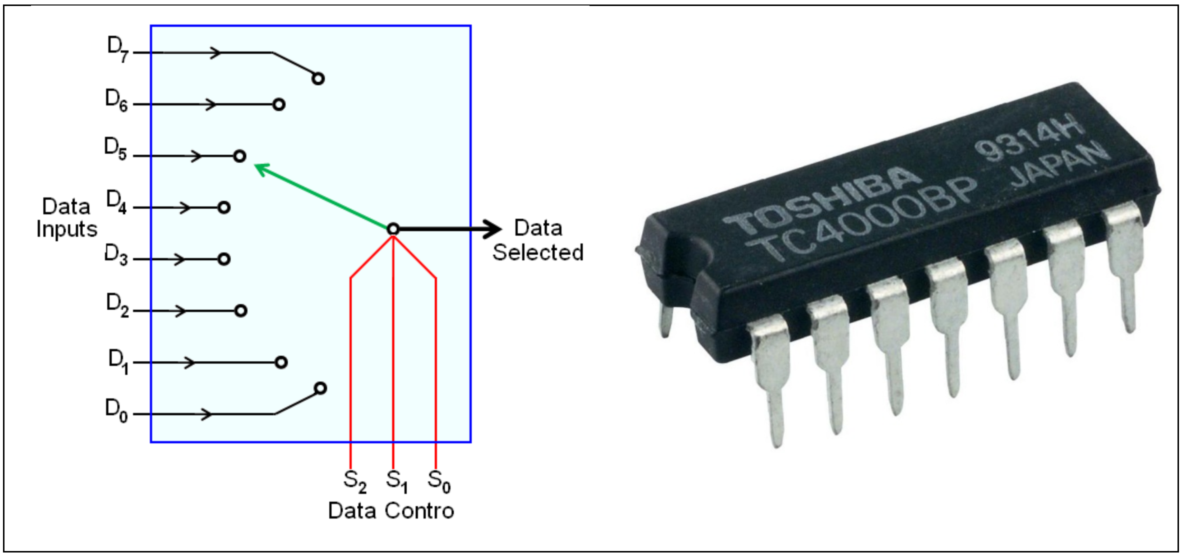


Fig. 3.1-5 8-Inputs Analog Multiplexer

DATA CONTROL			DATA SELECTED
S_2	**S_1**	**S_0**	
0	0	0	D_0
0	0	1	D_1
0	1	0	D_2
0	1	1	D_3
1	0	0	D_4
1	0	1	D_5
1	1	0	D_6
1	1	1	D_7

Table 3.1-1 Data Control and Data Selected

The data control pass determines which analog input is selected.

When the number of data control pass is (n), the max. number of analog inputs 2^n.

The max. number of analog inputs of the last multiplexer = $2^N = 8$ inputs

When the data control is held at (S_2 S_1 S_0) as (101), so the selected analog input is D_5 as indicated in table 3.1-1. There are many types of analog multiplexer depending on the max. number of inputs as the digital relay requires operating.

DIGITAL MULTIPLEXER

A digital multiplexer is a device that performs multiplexing; it selects one of many digital signals, which are already stored in memory locations to be called it and verify some processes.

Sometimes a group of inputs are required to fed to digital relay like phase currents (I_R, I_S, & I_T), line voltages (V_R, V_S, & V_T), neutral current I_N, etc in order to verify information about the fault; each input is selected individually as desired by the relay program through data control bus in the digital multiplexer, (Fig. 3.1-6).

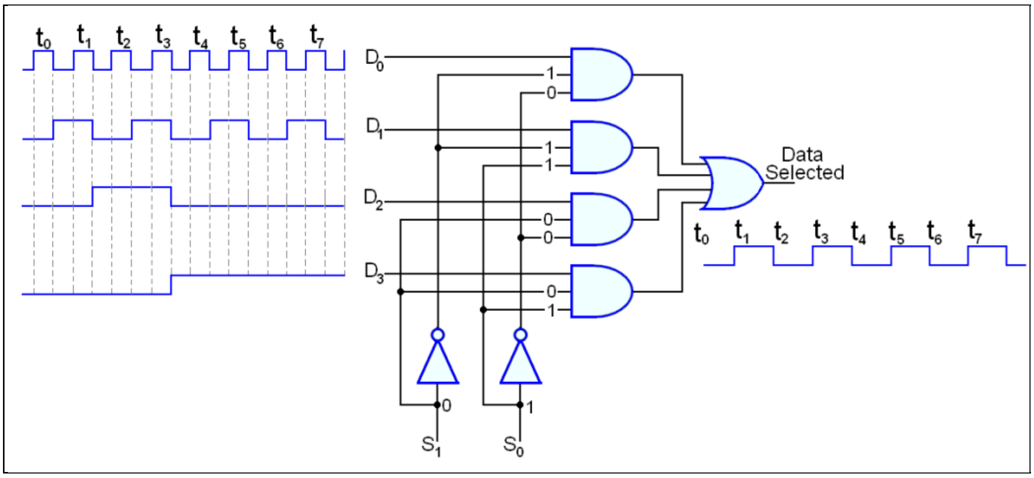


Fig. 3.1-6 Serial Digital Multiplexer

An electronic multiplexer makes it possible for several signals to share one device or resource, for example one A/D converter or one communication line, instead of having one device per input signal.

There are two types of digital multiplexer according to the type of data transfer; serial multiplexer and parallel multiplexer as shown in Fig. 3.1-7.

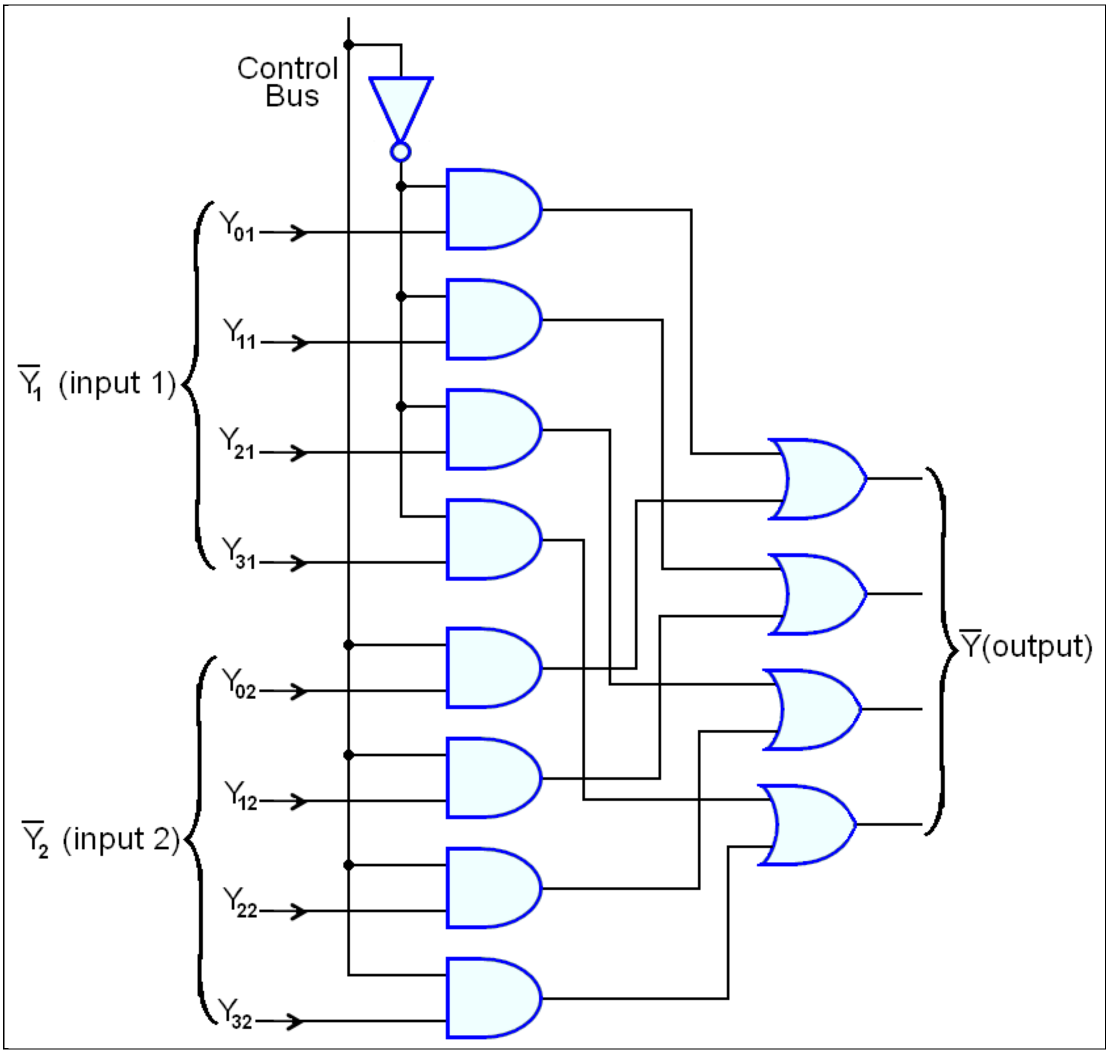


Fig. 3.1-7 Parallel Digital Multiplexer

CONVERSION SUBSYSTEM

The digital relay accepts signals in digital form. Therefore, analog signals must be converted into digital form before entering them to the digital processing to apply the required processes. Both voltage and current are analog quantities. As the micro-processor accepts only voltage signal in digital form, the current signal first is converted into proportional voltage signal, and then the voltage signal is converted into digital format to enter them to the microprocessor.

The A/D converter is used to convert analog signals into digital forms. If more than one analog quantity is to be converted into digital form by using only one A/D converter, analog multiplexers are used to select any analog quantity at a time for A/D conversion. For time-varying voltages such as ac voltage, a sample and hold(S/H) circuit is used to keep the desired instantaneous voltage constant during conversion period. This section discusses A/D converters, analog multiplexer, S/H circuits, and their interfacing to the microprocessor.

SAMPLE & HOLD CIRCUIT

A sample and hold circuit is used to interface real-world signals, by changing analog signals to a subsequent system such as an analog to digital converter. The purpose of this process is to hold the analogue value steady for a short time while the converter or other following system performs some operation that takes a little time.
In most circuits, a capacitor is used to store the analogue voltage and an electronic switch or gate is used to alternately connect and disconnect the capacitor from the analogue input. The rate at which this switch is operated is the sampling rate of the system, which is selected within the range that is in agreement with perfect aliasing. An ADC takes a finite time, known as conversion time (t_C) to convert an analog signal into digital form. If the input analog signal is not constant during the conversion period, the digital output of ADC will not correspond to the starting point analog input. A sample and hold (S/H) circuit is used to keep the instantaneous value of the rapidly varying analog signal (such as AC signal) constant during the conversion period. As the name implies that, the S/H circuit has two modes of operation namely Sample mode and Hold mode. When the logic input is high it is in the sample mode, and the output follows the input with unity gain. When the logic input is low; so it is in the hold mode and the output of the S/H circuit retains the last value of the signal amplitude until the command switches for the sample mode is released. The S/H circuit as shown in Fig. 3.1-8 consists of an operational amplifier charging a capacitor during the sample mode and retains the value of the charge of the capacitor during the hold mode.

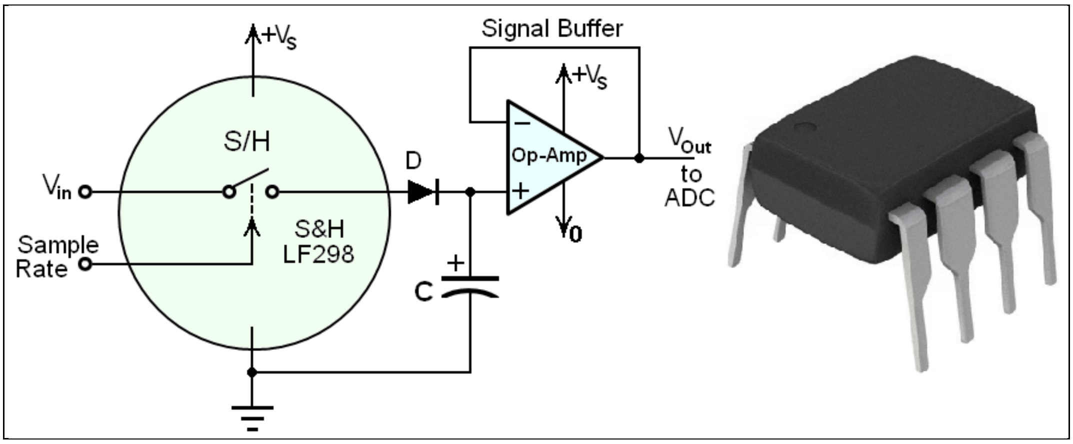


Fig. 3.1-8 Sample & Hold Circuit Configuration

Fig. 3.1-9 & Fig. 3.1-10 illustrate low and high sample and hold rate waveforms respectively.

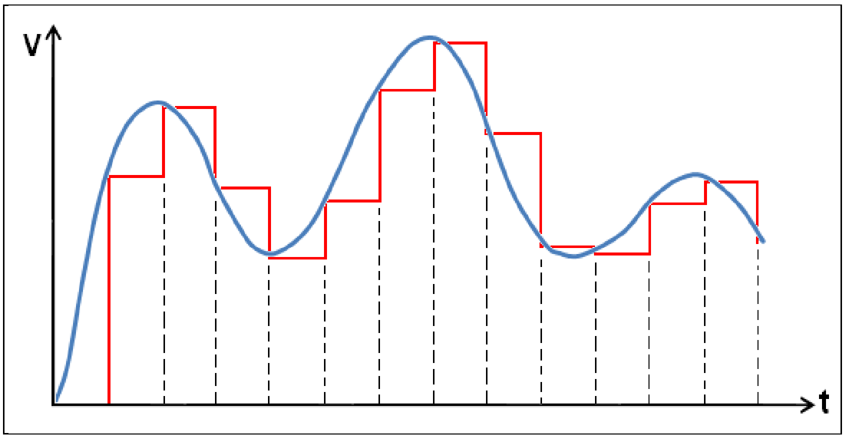


Fig. 3.1-9 Sampling Waveform with Poor Aliasing

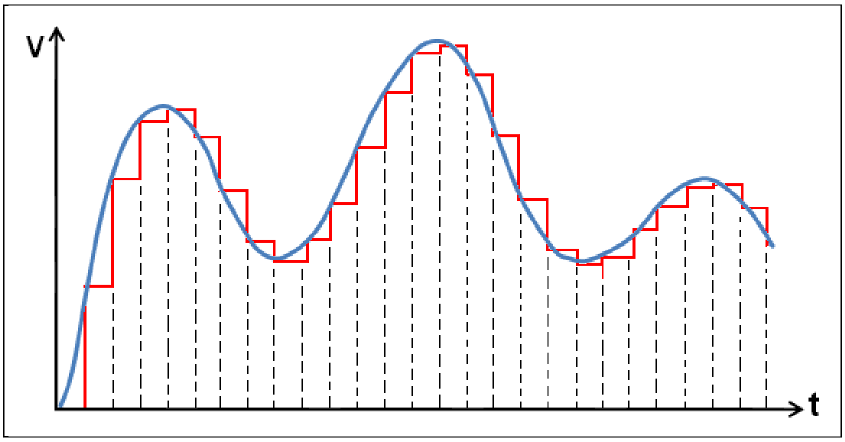


Fig. 3.1-10 Sampling Waveform with Perfect Aliasing

DIGITAL TO ANALOG CONVERTER

The digital to analogue converter is a device that converts a digital word into binary code, which consists of 8-bits into a DC voltage level proportional to its mathematical value. It is the reverse operation of analogue to digital converter (ADC).

It is an important part in the digital relay because its output works with the outside world of the digital system; like triggering power electronic devices, operating auxiliary relays, contactors, or direct tripping the circuit breaker depending on its output DC level. Various inputs to DACs are available, such as 4-bit inputs, 8-bit inputs, 16-bit inputs, or higher. The output of DACs may vary from zero to 5V or vary from -5V to +5V to work with negative digital word depending on its manufacturer and industrial number. Some DACs need external amplifier, as shown in Fig. 3.1-11, to amplify its output produce higher voltage to enable operation of high voltage devices. It is also used to match with the received operating device impedance.

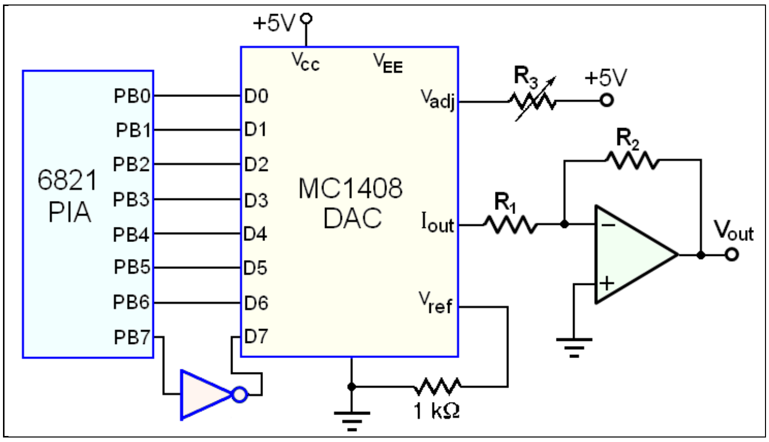


Fig. 3.1-11 Digital to Analogue Converter

ANALOG TO DIGITAL CONVERTER

An A/D converter is used to convert analog signals into digital forms. The digital output of the ADC is fed to the microprocessor for further processing. The successive approximation method is the most popular method for analog to digital conversion. This method has an excellent compromise between accuracy and speed.

In this method, when the microprocessor asks to read an analog input, the analog input divided into samples, the A/D receives start conversion zero pulse, the 8-bit digital counter start to count cycles came from clock oscillator. At each cycle, the counter counts up. The D/A converts that value into step DC signal that inter to an Op-amp to compare with the unknown analog signal. When the D/A signal still less than the analog input, the counter still counting up, until the D/A signal equals the unknown signal. Hence, the counter stops and produces the output in a digital form, Fig. 3.1-12.

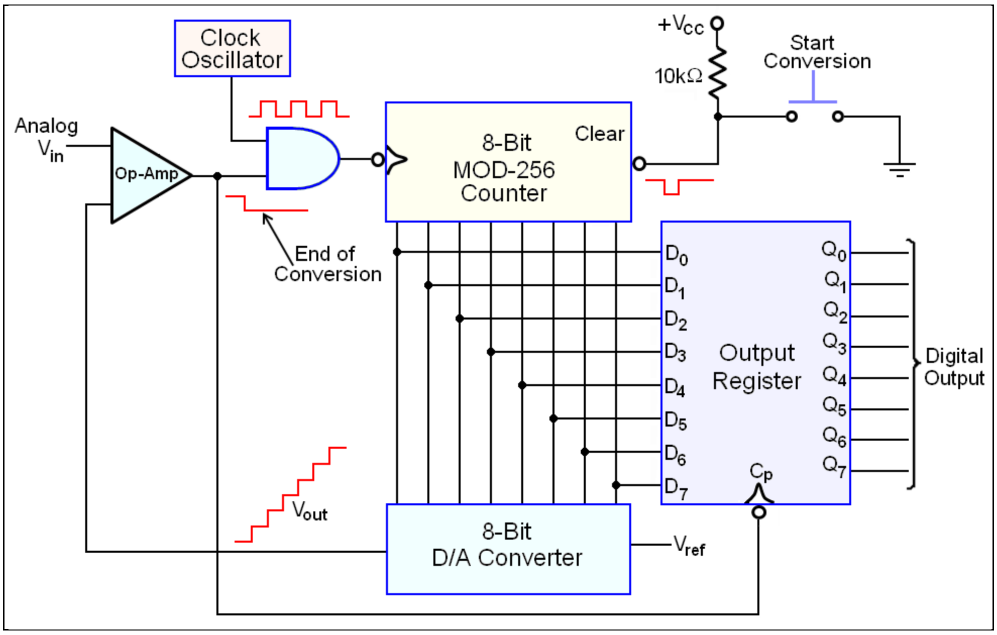


Fig. 3.1-12 Successive Approximation Analog to Digital Converter

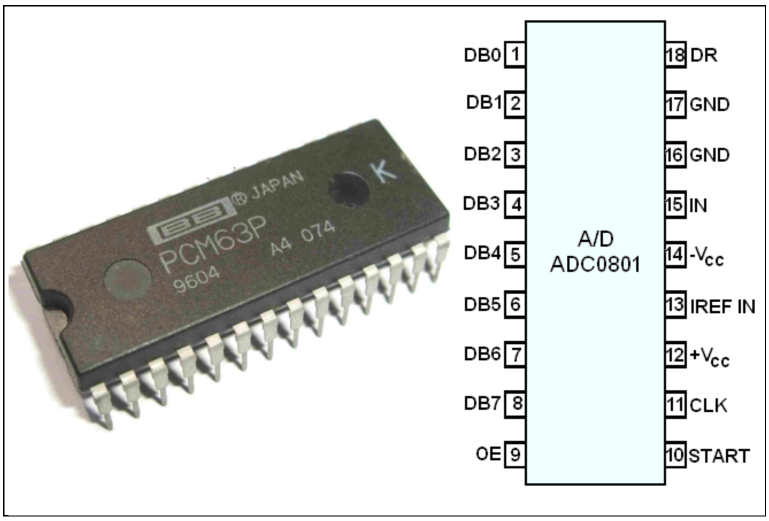


Fig. 3.1-13 Analog to Digital Converter IC and Pin Configuration

INTERFACING WITH A/D CONVERTER

The circuit for interfacing of ADC0800 to the 8085 microprocessor through programmable I/O port 8255 is illustrating in Fig. 3.1-14. A simple program to read the digital output corresponding to a single DC input voltage is developed. As the input DC voltage remains constant, the sample and hold circuit is not required in this case. The supply voltage of ± 5 VDC should be very accurate as it is used as reference voltage. This is obtained using op-amp circuit as shown in Fig 4.14.

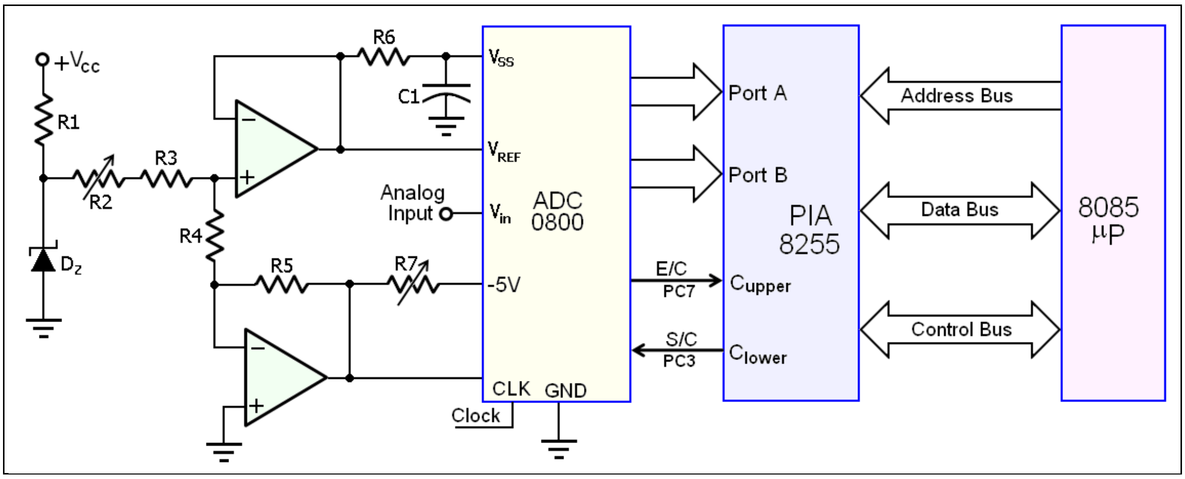


Fig. 3.1-14 Interfacing of ADC0800

INTERFACING OF ADC0800, MULTIPLEXER & S/H CIRCUIT

ADC takes a definite time depending on the clock frequency of the oscillator during the conversion from analog signals into digital form. The analog voltage should remain constant during the conversion period. For this purpose; a sample and hold, circuit is used. The use of S/H circuit is very essential in case of time varying signals such as ac voltage. The S/H circuit samples the instantaneous value of the ac signal at the desired instant and holds it constant during the conversion period of ADC. S/H circuit is also used to obtain a number of samples of time varying signals at some interval known as sampling interval (T_S).

An analog multiplexer is used to select signal of any channel from the multi-input channels and transfer this signal to its output for A/D conversion.

In order to obtain a number of simultaneous samples of more than one signal, S/H circuit is incorporated in every channel of the multiplexer to which input signals are applied, and the sampling pulse to all the S/H circuits is sent simultaneously through the microprocessor at the required sampling interval. The 8253 counter/timer is used to generate the sampling pulse for the S/H circuit. It can also be used to generate clock for the A/D converter. The number of digital output bits of the ADC component is proportional to the resolution of the conversion process.

DIGITAL PROCESSING SUBSYSTEM

MICROPROCESSOR

A microprocessor is a programmable digital device that performs all the functions of the CPU of a computer and is implemented in one IC package using multi function component technology. Microprocessor acts the latest development in the field of computer technology. It can fetch instructions from memory, decode and execute them, perform arithmetic and logic operations, accepts data from input devices, and send results to control output devices. The main segments of a microprocessor are the same as the general CPU, i.e. Arithmetic and Logic Unit (ALU), Timing and Control Unit, and Register Array as shown in Fig. 3.1-15.

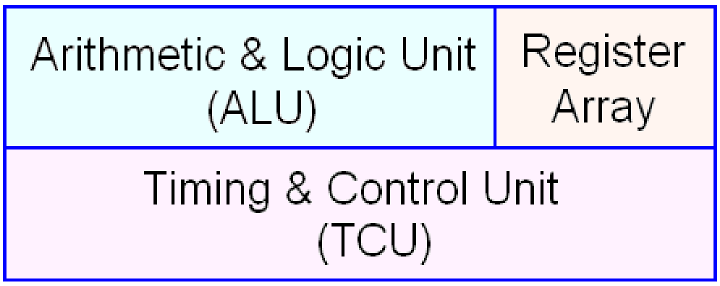


Fig. 3.1-15 Schematic diagram of a CPU

The microprocessor in combination with memory and input/output devices forms a microcomputer. The low cost, small size and programmability of microprocessors make them suitable for large number of applications.

The main components of a digital computer are the CPU, memory, input device and output device.

CENTRAL PROCESSING UNIT (CPU)

The CPU fetches instructions from the memory and executes them to perform a specified task. It stores results in the memory or sends results to the output device as per the instruction contained in the program. The CPU controls and communicates with memory and input/output devices.

ARITHMETIC & LOGIC UNIT (ALU)

ALU acts the main segments of the CPU, which performs arithmetic and logic operations.

ARITHMETIC OPERATIONS

It is the responsible segment to verify the basic calculations, such as addition, subtraction, multiplication, deviation,

LOGIC OPERATIONS

It is the responsible segment to verify the logic functions, such as ANDing, ORing, Inverting, Noring, EXORing, NANDing, etc….

TIMING AND CONTROL UNIT (TCU)

This segment responses to provide the necessary timing and control signals for the entire operations in the computer.

REGISTER ARRAYS

It is a number of temporary memory locations used to keep data during processes that exist in the microprocessor and include the following:

ACCUMULATOR

8-bit register used to receive and deliver the input signal while applying any process for that signal. Some processors have more than accumulator for best performance.

GENERAL PURPOSE REGISTERS

They are number of registers used for temporary storage during the execution of the relay program. Each register is defined with its name and address. The number of these registers depends on the processor manufacture industrial number and exists in its data sheet.

PROGRAM COUNTER (PC)

It is 16-bit register exist in the CPU to count up the number of execution instructions that verified in the relay program.

STACK

Stack is a part of memory that exists in RAM. It is used to store the contents of the CPU registers, and fill its locations as first input last output.

STACK POINTER (SP)

It is 16-bit register exists in the CPU to monitor the capacity of the stack. It contains the address of the stack top.

STATUS REGISTER FLAGS

It is 8-bit register that describes detailed information about the contents of accumulator register after applying certain process. Each bit describes a condition as follow:

Carry (C): When the result of an arithmetic operation results in a carry, this flag is set: otherwise, it is reset.

Parity (P): When the result of the operation contains an even number of 1s, it is set; otherwise, it is reset.

Interrupt (I): When the digital relay is interrupted by an external event, the main program stops and subroutine program is running, this flag is set; otherwise, it is reset.

Zero (Z): When the result of an arithmetic or logic operation is zero, this flag is set, otherwise, it is reset.

Overflow (V): When the contents of the 8-bit location exceed 255, this flag is set; and the location contents become the reminder of the value.

Negative (N): When the result of an arithmetic operation is negative, this flag is set to 1; otherwise, it is reset.

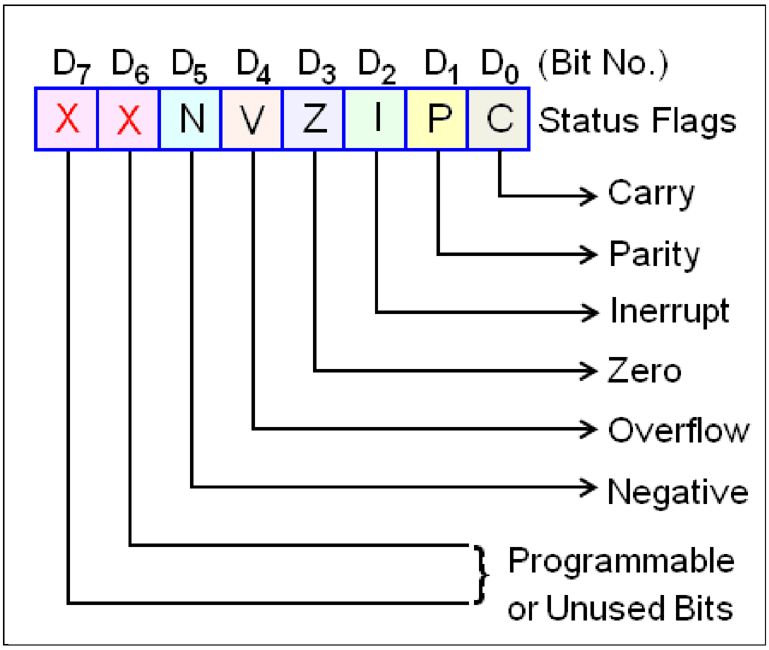


Fig. 3.1-16 Processor Status Word Configuration

The first six flags can increases to complete eight bits by adding two programmable flags according to the user program or adding 2-zeros, in order to complete the 8-bit word. The arranging of these bits is varying from processor to another according to the manufacture data sheet.

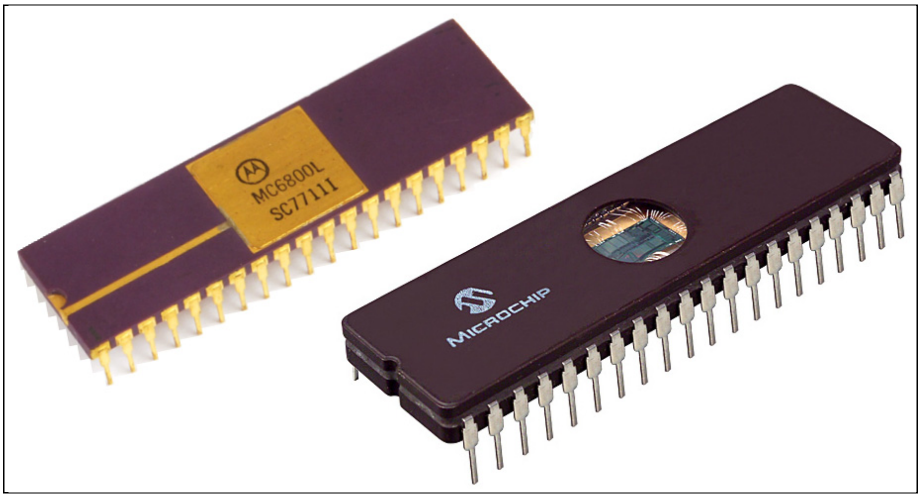


Fig. 3.1-17 Different Types of Microprocessors

Fig. 3.1-18 shows the block diagram of a typical microprocessor in which the various units are connected by three distinct types of buses; namely the address bus, the data bus and the control bus. A bus is a set of lines over which electrical signals or information is transmitted from any of the several sources to any of the several destinations. The width of a bus is the number of signal lines that constitute the bus. The advancement in integrated circuit technology has taken place up to such an extent that single-chip microcomputers are available these days in which the microprocessor (CPU), memory, and I/Os are all fabricated on the same chip. This single-chip microcomputer is called microcontroller, which offers limited capabilities.

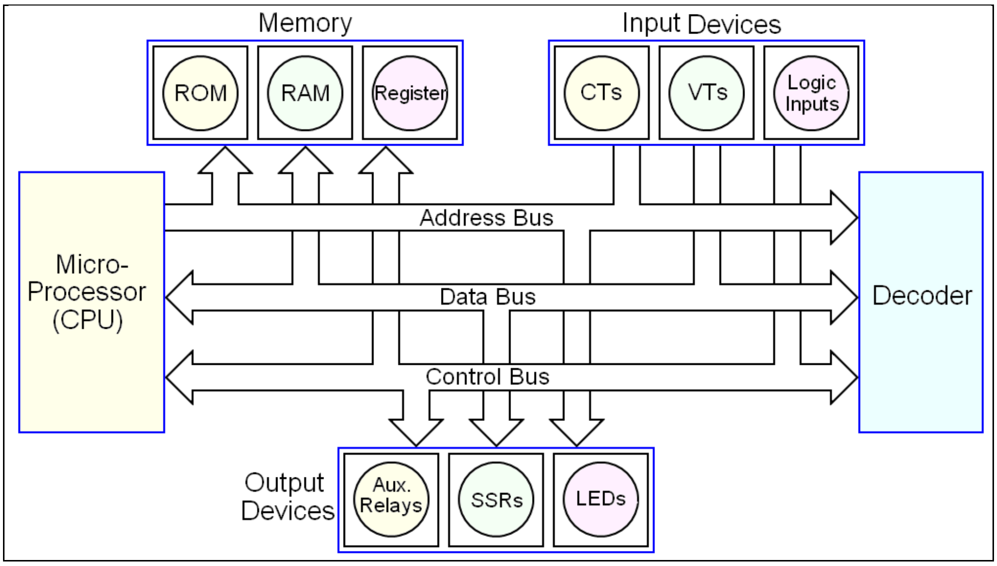


Fig. 3.1-18 Block diagram of a typical microprocessor

INPUT/OUTPUT DEVICES

The microprocessor communicates with the outside world through input/output devices. It receives binary data and instructions from the input devices and sends data to output devices. The input and output devices are known as peripherals. A keyboard, simple switches, teletypes, and analog to digital (A/D) converters are examples of input devices. The examples of output devices are light emitting diodes (LEDs), seven segment display, screens , printers, and digital to analog (D/A) converters.

SEMICONDUCTOR MEMORIES

Memories are used to store binary information such as instructions, data and results, and to provide that information to the microprocessor whenever required. Semiconductor memories are widely used in the microprocessor-based systems, because they are available in IC form and require less space. There are two main types of semiconductor memories, namely random access memory (RAM), and read only memory (ROM). There are different types of RAM and ROMs as described in the subsequent sections.

RANDOM ACCESS MEMORY (RAM)

RAM is a chip memory that has certain capacity of memory locations. It is volatile memory that erases its contents as soon as the supply voltage is off. It is used to store temporary results of the CPU registers during interrupts and before producing signals.

READ ONLY MEMORY (ROM)

It is a nonvolatile memory that it keeps storing its memory with or without supply voltage. The data can only be read from ROM. It is used to store permanent digital relay program so it has large capacity of memory. There are several types of ROM that can use in the digital relay; following are the different types of ROM.

MASK-PROGRAMMABLE ROM

This type of ROM is programmed at the factory during manufacture. The manufacturer makes special masks for fabrication of the ROM chip, as per the specification of the users. The main disadvantage of this type of ROM is that once fabricated, its contents cannot be altered.

PROM

The name PROM stands for programmable read only memory. The programming of PROM is done by the user. PROM Programmer is used for this operation. The disadvantage of this type of ROM is that its programming can be done only once and no chance to change the written reprogram.

EPROM

EPROM stands for erasable programmable read only memory. The contents of the EPROM can be erased by exposing it to ultraviolet light for several minutes (10 to 20 minutes) through a quartz window provided on the chip. Then the memory chip can be reprogrammed again with the help of an EPROM programmer. The EPROM chip has to be taken out of the system for erasing before downloading the new contents, after downloading complete a sticker should be fixed on the quartz window to prevent erasing, Fig. 3.1-19.

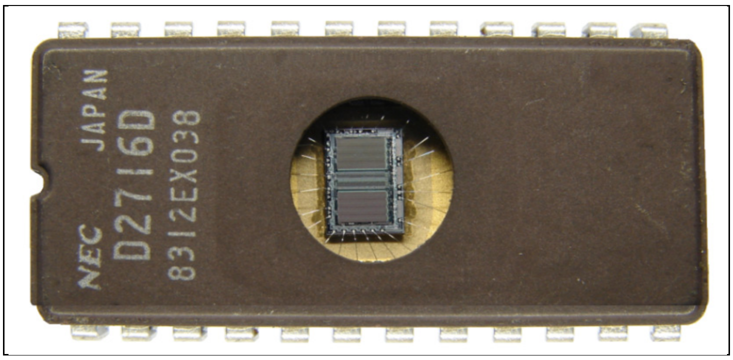


Fig. 3.1-19 EPROM Component

EEPROM

It stands for electrically erasable programmable read only memory. The contents of this memory can be altered or erased by using electrical signals instead of ultraviolet light. The memory chip needs not to take out of the system board for erasing. The alteration in contents is made in few milliseconds.

I/O PORTS AND PROGRAMMABLE PERIPHERAL INTERFACE

The microprocessor communicates with the outside world through input/output devices, which are also known as peripheral devices. The places for loading data from input devices to the microprocessor and loading data into the output device from the microprocessor are called I/O ports. Therefore, the transfer of data between input/output devices and the microprocessor takes place through I/O ports. Input/output devices may be Analog and/or Digital types that are interfaced to the microprocessor through Analog and Digital I/O ports, respectively, as illustrated in Fig. 3.1-20.

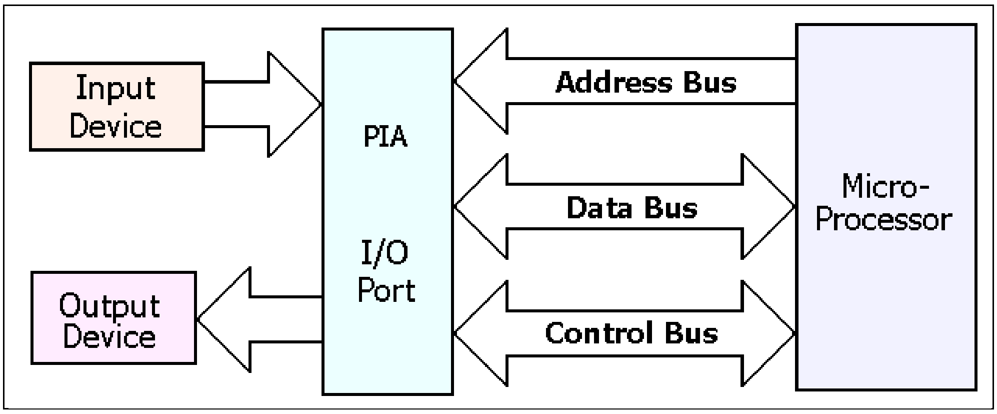


Fig. 3.1-20 Interfacing of I/O Device through I/O Port

They may be either non-programmable or programmable. Non-programmable I/O ports is configured for a limited number of modes by changing the hardware interconnections; whereas programmable I/O ports can be configured for different modes by writing suitable control words into the on-chip control register which does

not require any change in hardware interconnections. At present a variety of programmable I/O ports known as programmable peripheral interface or programmable interface adapter are available in the form of single IC chip.

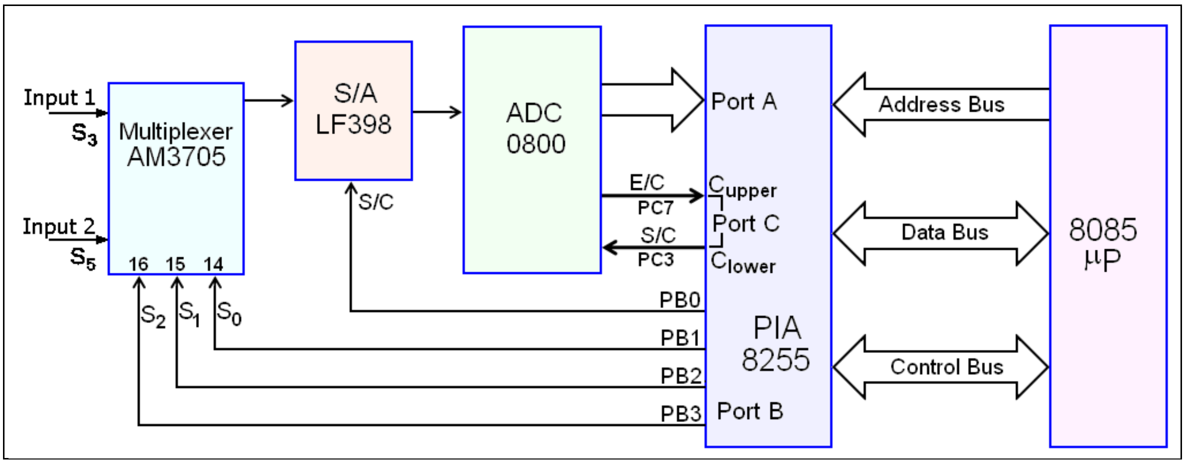


Fig. 3.1-21 Interfacing of ADC, Multiplexer and S/H Circuit

CRYSTAL OSCILLATOR

A crystal oscillator is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a very precise frequency. This frequency is commonly used to keep track of time (as in quartz wristwatches), to provide a stable clock signal for digital integrated circuits, and to stabilize frequencies for radio systems, as shown in Fig. 3.1-22.

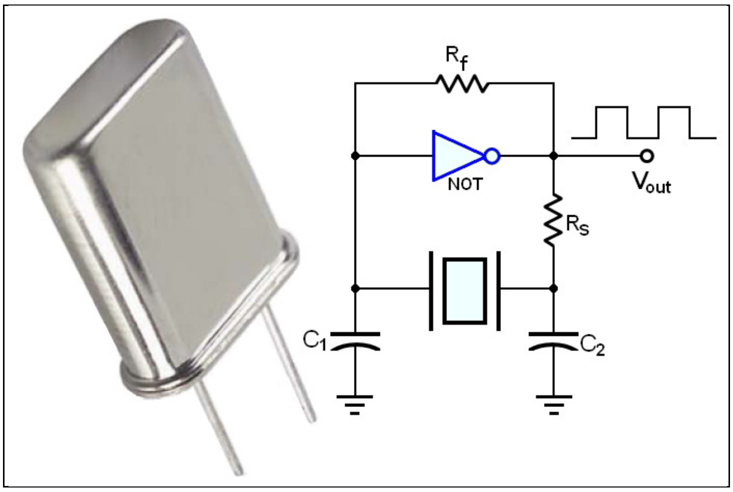


Fig. 3.1-22 Crystal Oscillator Configuration Circuit

The most common type of piezoelectric resonator used is the quartz crystal, so oscillator circuits designed around them are known as "crystal oscillators."

Quartz crystals are manufactured for frequencies from a few tens of kilohertz to tens of megahertz. Most are used for consumer devices such as wristwatches, clocks, radios, and computers. Quartz crystals are also found inside test and measurement equipment, such as counters, signal generators, and oscilloscopes.

Clock oscillator is the direct application for the crystal that generates square wave with a certain amplitude and frequency range. It is used in static relays to determine the delay time for the backup signals. In the digital relay, it is used to execute the program instructions. Each instruction is defined by number of cycles, each cycle must agrees with the oscillator cycle time. There are many types of clock oscillators. Crystal oscillator is the most famous type that used in the digital relays, as shown in Fig. 3.1-22.

SUMMARY

This lesson summarizes the following outlines:

- Illustrating the importance of microprocessor in the digital relay.
- Describing the memory types used in digital relay.
- Demonstrating the hardware structure of digital relay.
- Verifying the applications of analog and digital multiplexer.
- Describing the interface between I/O ports and the microprocessor.
- Verifying the importance of A/D and D/A converters in the digital relay.
- Illustrating the use of S/H circuit in the digital relay.

GLOSSARY

Algorithm:	Execution for different functions
Surge protection:	Protection against voltage spikes
Aliasing:	Method to acquire a deeper understanding of the sampled waves
Low pass filter:	Filter circuit that passes low frequency signals and blocks higher frequencies.
ROM:	Read Only Memory
PROM:	Programmable ROM
EPROM:	Erasable programmable ROM
EEPROM:	Electrical erasable programmable ROM
Register:	A memory unit that stores one word
Byte:	Eight bits of data word
Accumulator:	A master register found in the CPU of microprocessor
Parity:	A bit that checks even or odd number of 1s
PIA:	Peripheral interface adapter
ALU:	Arithmetic and logic unit used for Arithmetic and logic mathematical operations

REVIEW EXERCISE

Choose the correct answer for each of the following:

1. The function of multiplexer is to ………………………………………………………..

a) Select the program instruction.

b) Select one output among multi outputs.

c) Select one port to pass its input word.

d) Select one chip of the microprocessor system.

2. The function of the decoder is to ………………………………………………………

a) Select one output port to pass the input word

b) Select one input among multi inputs.

c) Select one instruction from the program.

d) Select one chip of the microprocessor system

3. The function of A/D is to ………………………………………………………………

a) Convert from analog to digital.

b) Convert digital to analog.

c) Convert decimal to hexadecimal.

d) Concert parallel to serial 8-bit word

4. A good CPU performance is dependent on ………………………………………

a) The number of the chip terminals

b) The level of the input analog voltage.

c) The number of the verifying instructions in parallel.

d) The number of the internal registers.

5. The stack is ……………………………………………………………………………

a) A part of the program found in the ROM.

b) A part of the locations found in the RAM.

c) A register found in the CPU.

d) A register found in the PIA

6. Clock oscillator is used to ……………………………………………………………….

a) Generate sine wave
b) Generate square wave.
c) Enable the PIA outputs.
d) Enable the CPU outputs.

7. The stack pointer is ……………………………………………...…………………

a) A part of the program found in the ROM.
b) A part of the locations found in the RAM.
c) A register found in the CPU.
d) A register found in the PIA

8. The program counter is ……………………………………………………………

a) A register found in the ROM.
b) A register found in the CPU.
c) A register found in the RAM.
d) A register found in the PIA.

9. The ALU performs ………………………………………………………………

a) The program instructions.
b) The arithmetic and logic operations.
c) The input signal conversion
d) The storing of the calculation results

10. The digital relay program is stored in …………………………………………...

a) PIA
b) CPU
c) RAM
d) ROM

11. The output port signals are determined by ………………………………………

a) The multiplexer.
b) The demultiplexer.
c) The sample and hold.
d) Analog to Digital Converter

12. The width of the data bus depends on ……………………………………………

a) The number of A/D output bits.
b) The value of the clock frequency.
c) The value of the DC supplies voltage.
d) The capacity of the ROM

13. The resolution of the A/D converter depends on ………………………………

a) The value of the clock frequency.
b) The value of the DC supply voltage.
c) The number of the A/D output bits.
d) The capacity of the RAM

14. The sign of a signal value can be detected in …………………………………..

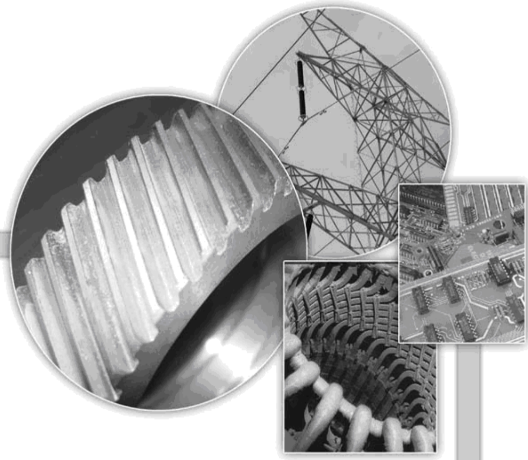
a) The PSW register.
b) The accumulator.
c) The temporary register.
d) The RAM

15. The width of the address bus depends on ………………………………………

a) The number of the A/D output bits.
b) The maximum number of locations of the memory map.
c) The value of the clock frequency.
d) The capacity of the RAM

16. The sample & hold is connected to the A/D converter through ………………...

a) Static switch.
b) Amplifier.
c) Capacitor coupling.
d) Signal buffer.



LESSON 3.2

PROGRAMMING OF DIGITAL RELAYS

LESSON 3.2
PROGRAMMING OF DIGITAL RELAYS

OVERVIEW

This lesson describes a complete arrangement for digital relay hardware illustrating the flowchart of its programming software.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Identify flowchart diagrams and its components.
- Verify flowchart for digital timers.
- Verify building up digital microprocessor time overcurrent relay; including its program flowchart.
- Illustrate the digital distance relays; including its program flowchart.
- Describe the digital directional reverse power and overcurrent relay.
- Identify how to measure resistance and reactance of TL in the digital relay.
- Illustrate the advantages of multifunction numerical relays.

INTRODUCTION

The digital relay consists of hardware, which contains components and electronic circuits (printed circuit boards) and software, which is needed to control the duty of the hardware. There are two types of software, manufacturer software, which control the relay type, performance, characteristics, relay options, and its sequence of operations. This software is masked that unavailable to the user, and called firmware.
The other type of software programming is available to the user to control the relay setting, the fault conditions, entering date and time, station information, the protected device parameters, and many other things depending on the manufacturer programming. The internal software program is divided into many programs, each program has a certain start and end address. All the internal programs are written cascaded in a memory map and the relay operations transfer between them.

FLOWCHART COMPONENTS

A flowchart is a type of diagram that represents an algorithm or process, showing the steps as boxes of process, and their order by connecting these with arrows. This diagrammatic representation can give a step-by-step solution to a given problem. Process operations are represented in these boxes, and arrows connecting them represent flow of control. Data flows are not typically represented in a flowchart, in contrast with data flow diagrams; rather, they are implied by the sequencing of operations. Flowcharts are used in analyzing, designing, documenting or managing a process or program in various fields

START AND END SYMBOLS

This symbol is represented by circle or oval. It usually contains the word "Start" or "End", Fig. 3.2-1a. This symbol means that the program starts at a certain address.

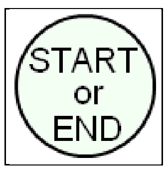


Fig. 3.2-1a

READ SYMBOL

The symbol of Fig. 3.2-1b is used to enter a certain data to the digital relay. These data either an analog (current, voltage, temperature, etc ….) and/or logic (switches or circuit breakers open/close).

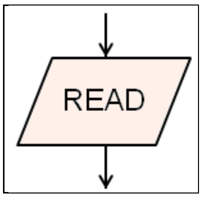


Fig. 3.2-1b

PROCESS SYMBOL

The symbol of Fig. 3.2-1c is used to apply certain algorithm operation, to calculate certain operation depending on the entered data. Such as calculating Vars from phase current, and line voltage.

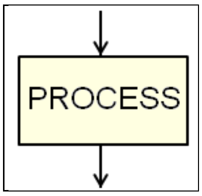


Fig. 3.2-1c

CONDITION SYMBOL

The symbol of Fig. 3.2-1d is used to compare two values or to verify the equality (A = B), the inequality (A ≠ B) to determine certain condition, the situation (normal or fault). The (YES) condition means go forward through the flowchart, the (NO) condition means jump up or down to verify certain process

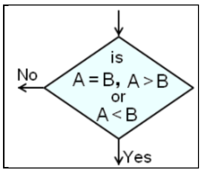


Fig. 3.2-1d

The last symbols are used together to form a complete flowchart for a part of the main program (subprogram)

SOME OF THE INTERNAL PROGRAMS

- Initializing input/output ports.
- Entering analog data.
- Entering logic data.
- Timing programs.
- Algorithm operations.
- Comparator operation.
- Overcurrent relay operation.
- Over/under voltage operation.
- Directional relay operation.
- Differential operation.
- Impedance computation.
- Distance relay operations.

DIGITAL TIMER

The timers in the electromechanical and static relays are built from hardware and setting elements; which can be set to the required predetermined value. Sometimes many timers with different settings may be needed in the same relay, so a lot of hardware must be required to build up. In digital timers, only software program can be added to create timer. A small subroutine is used to set any timer, Fig 3.2-2.

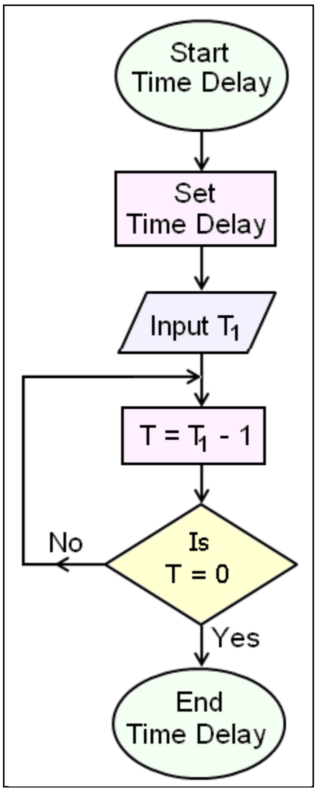


Fig. 3.2-2 Flowchart for Timer Subroutine

The setting for time delay depends on the clock oscillator frequency of the microprocessor and the program timing instructions. In Fig 3.2-2, the value of T_1 for example is determined from lookup table, which stored in the program memory, and then calibrated to agree with the relay clock. At the end of delay time subroutine the program returns to continue its operation as directed in the program flowchart. Note, a lot of time delays can be added to the same program flowchart, just by changing T_1 value for the new delay.

The (Set Time Delay) step is determined from the relay characteristics or the relay look-up table, the (Input T_1) step means that the calculated value of the last step is entered to the timer process as a numeric value, the looping between (Is T = 0) step and (T = T – 1) step take the total delay time depending on the verified delay time for each instruction multiplying by (T). A long time delay also can be done by using nested loops inside the timing loop to determine long delays.

DIGITAL TIME OVERCURRENT RELAY

An overcurrent relay is the simplest form of protective relay, which operates when the current in any circuit exceeds a certain predetermined value, i.e. the pick-up value. It is widely used for the protection of distribution lines, industrial motors, and equipment. Using a multiplexer, the microprocessor can sense the fault currents of a number of circuits.

If the fault current in any circuit exceeds the pick-up value, the microprocessor sends a tripping signal to the circuit breaker of the faulty circuit. As the microprocessor accepts signals in voltage form, the current signal derived from the current transformer is converted into a proportional voltage signal using a current to voltage transducer. The AC voltage proportional to the load current is converted into DC using a precision rectifier. Thus, the microprocessor accepts DC voltage proportional to the load current. The block schematic diagram of the relay is shown in Fig. 3.2-3. The start symbol in the flowchart mains the program is transferred to that address to begin the overcurrent relay operation. The output of the rectifier is fed to the multiplexer. The microcomputer sends a command to switch on the desired channel of the multiplexer to obtain the rectified voltage proportional to the current in a particular circuit. The multiplexer output is fed to the A/D converter to obtain the signal in digital form. An A/D has been used for this purpose. The microcomputer sends start conversion (S/C) signal to the ADC. The microcomputer reads the end of conversion (E/C) signal to examine whether the conversion is over or not. As soon as the conversion is over, the microcomputer reads the current signal in digital form and then compares it with the pick-up value.

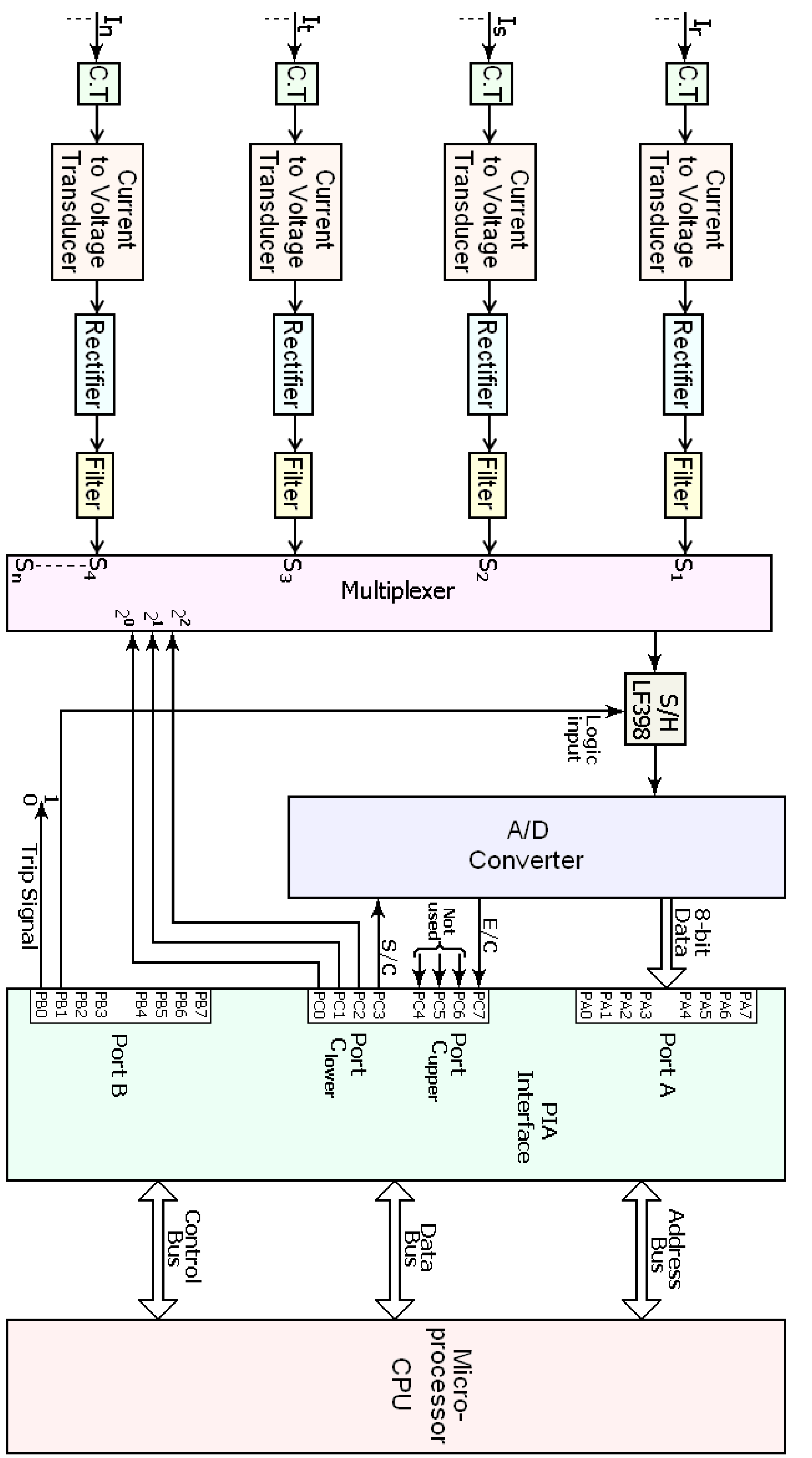


Fig. 3.2-3 Block Diagram of Digital Time Overcurrent Relay

In the case of a definite time overcurrent relay, the microcomputer sends the tripping signal to the circuit breaker after a predetermined time delay if the fault current exceeds the pick-up value. In case of instantaneous overcurrent relay there is no intentional time delay.

In order to obtain inverse-time characteristics, the operating times for different values of currents are noted for particular characteristics. These values are stored in the memory in tabular form. The microcomputer first determines the magnitude of the fault current and then selects the corresponding time of operation from look-up table.

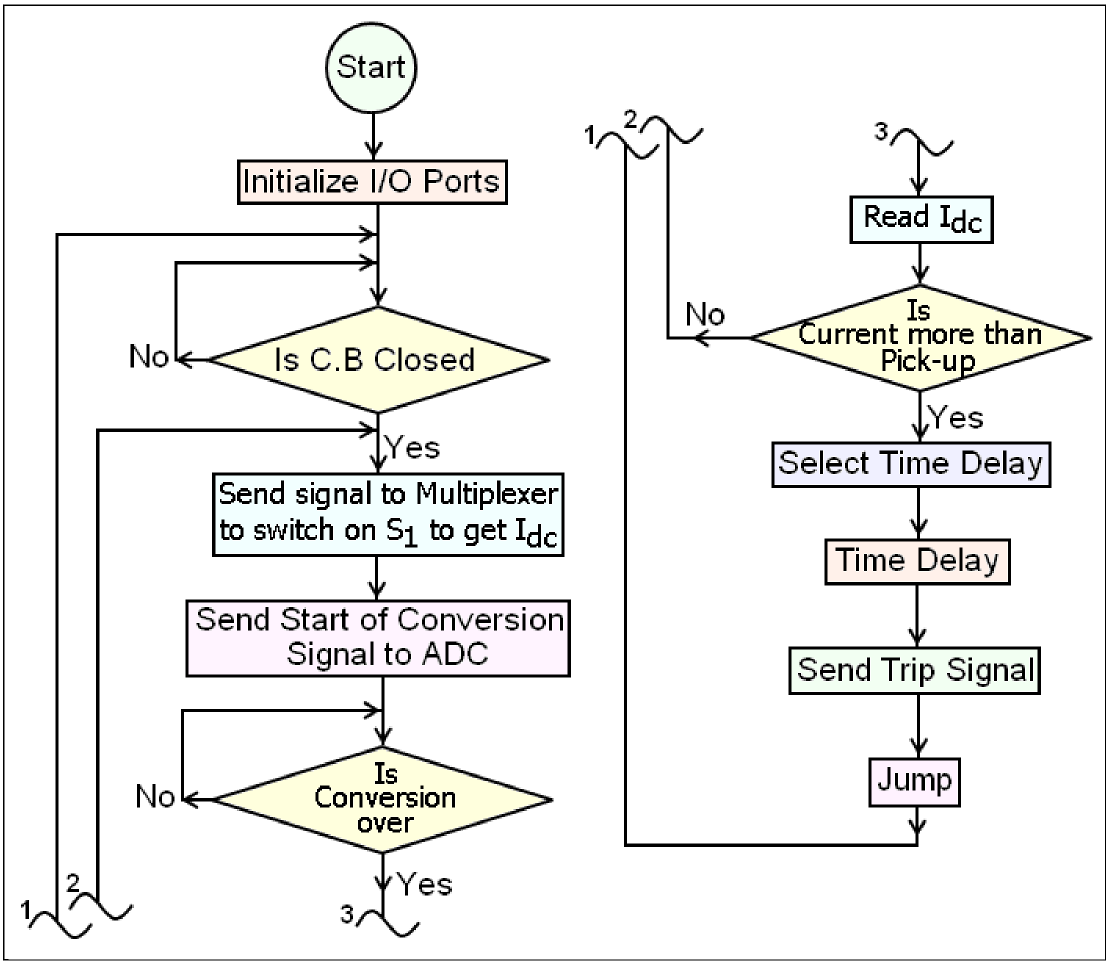


Fig. 3.2-4 Flowchart for Time Overcurrent Relay

A delay subroutine is started and the trip signal is sent after the desired delay. Using the same program, any characteristic such as IDMT, very inverse or extremely inverse can be realized by simply changing the data of the look-up table according to the desired characteristic to be realized.

The microcomputer continuously measures the current and moves in a loop and if the measured current exceeds the pick-up value, it compares the measured value of the current with the digital values of current given in the look-up table in order to select the corresponding count for a time delay. Then it goes in delay subroutine and sends a trip signal to the circuit breaker after the predetermined time delay. The program flowchart is shown in Fig. 3.2-4.

In order to avoid false tripping of an overcurrent relay due to transients the program can be modified slightly. The program flowchart is shown in Fig. 3.2-5. When the fault current exceeds the pick-up value, the fault current is measured once again by the microprocessor to confirm whether it is a fault current or transient. In case of any transient of short duration, the measured current above pick-up value will not appear in the second measurement.

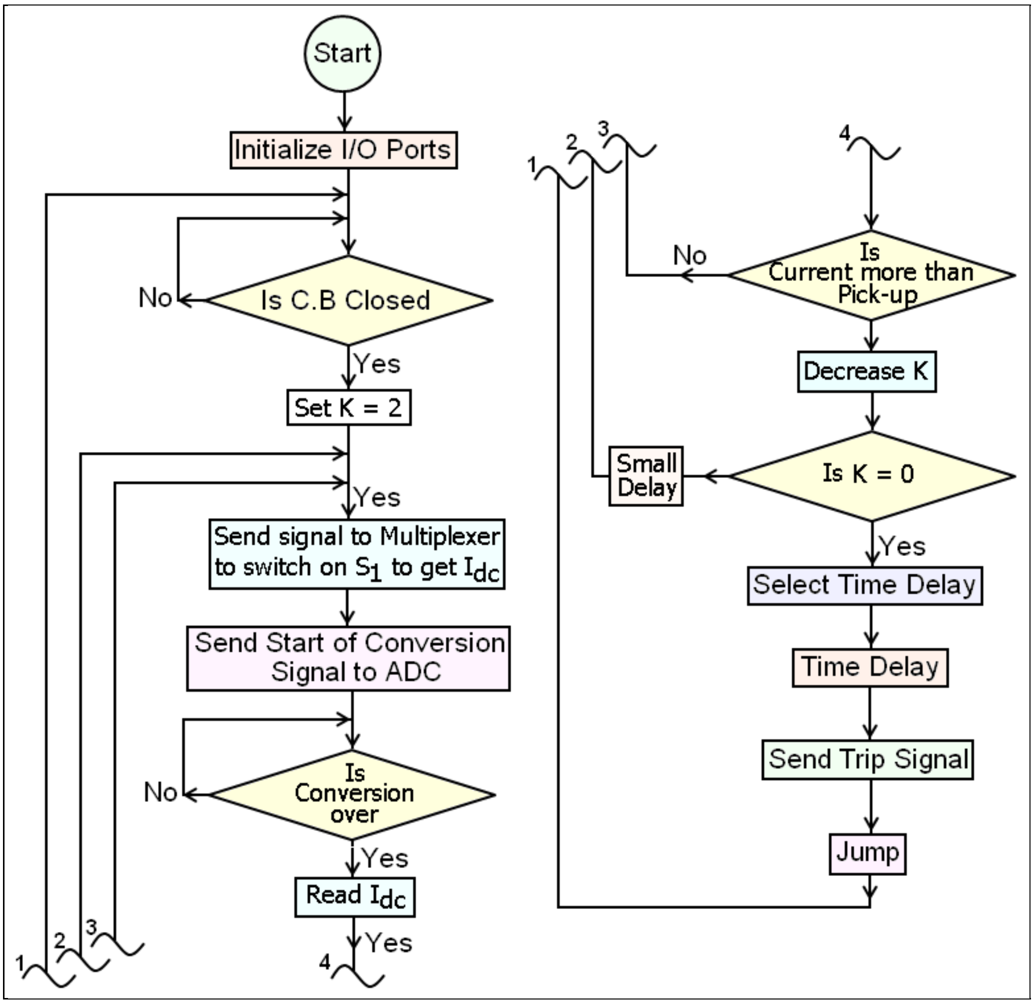


Fig. 3.2-5 Eliminating False Tripping in Case of Transient Fault

However, if there is an actual fault, it will again appear in the second measurement also, and then the microprocessor will issue a tripping signal to disconnect the faulty part of the system. Note the same hardware structure of the digital time overcurrent relay can be used in the above modification to the relay and any feature modification can be added through the software program.

IMPEDANCE DISTANCE RELAY

The characteristic of an impedance relay is realized by comparing voltage and current at the relay location. The ratio of voltage V to current I give the impedance of the line section between the relay location and the fault point. The rectified voltage V_{dc} and rectified current I_{dc} are proportional to V and I, respectively. Therefore, comparison between V_{dc} and I_{dc} are used. The following condition should be satisfied for the operation of the relay.

$$K_1\, V_{dc} \;<\; K_2\, I_{dc}$$

or

$$V_{dc}/I_{dc} \;<\; K_2/K_1$$

Then:

$$V/I \;< K$$

Or

$$Z \;< K$$

Where K_1, K_2 and K are constants dependant on the impedance setting of each zone of the transmission line. The values of K for different zones of protection are calculated and stored in the memory as data to obtain the desired characteristic. The characteristics of the three-zone impedance relays are divided into three zones Z_1, Z_2 & Z_3 are the values of impedances for I, II and III zones of protection, respectively. The time delays for each stage t_1, t_2, and t_3 are the operating times for I, II, and III zones of protection, respectively. As the impedance relay is non-directional, a directional unit is also incorporated to give a directional feature so that the relay can operate for the fault in forward direction only. The block schematic diagram of the interface for the impedance relay is as shown in Fig. 3.2-6.

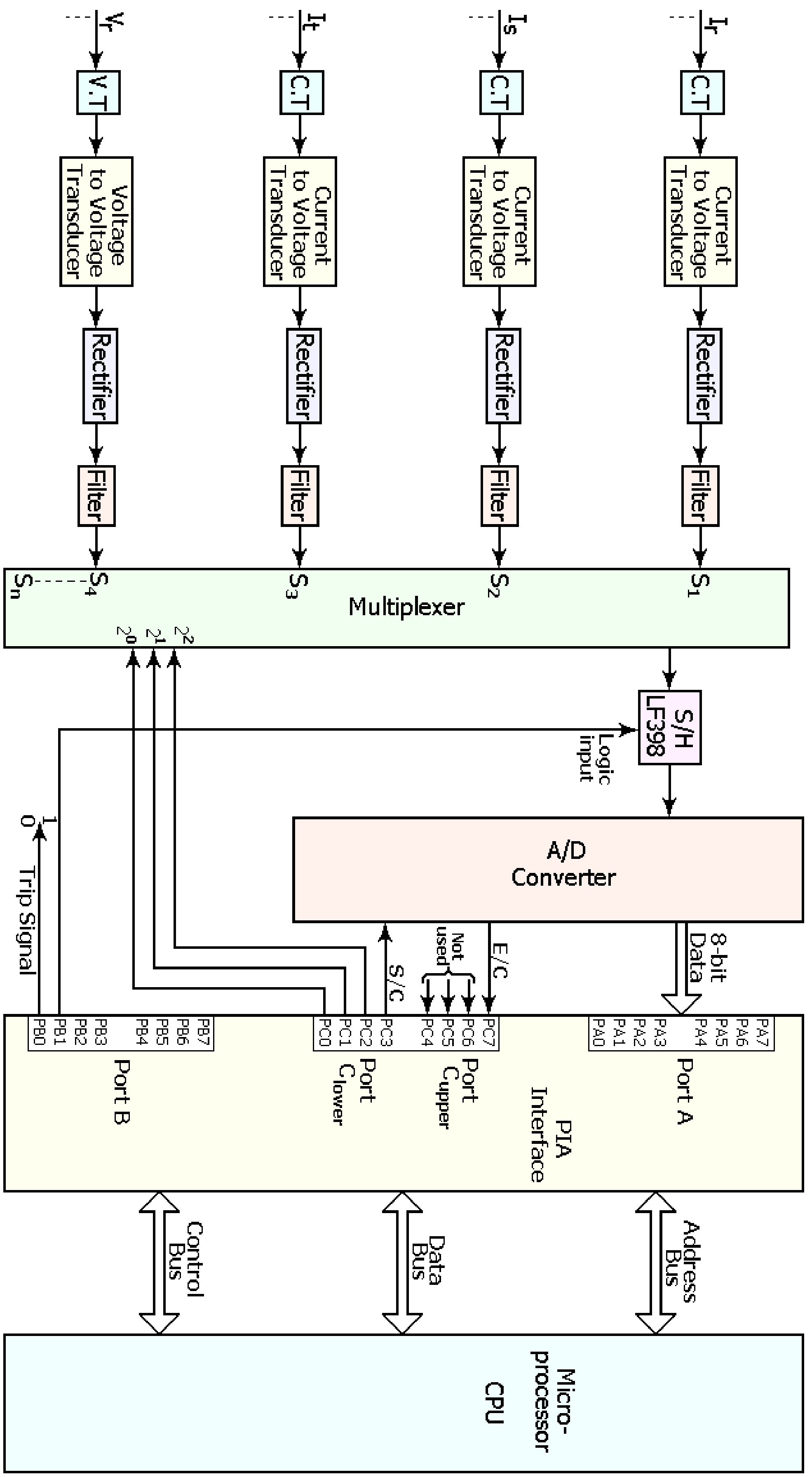


Fig. 3.2-6 Blockdiagram of Interfacing Impedance Distance Relay

The levels of voltage and current signals are stepped down to the electronic level by using potential and current transformers. The current signal derived from the current transformer is converted into proportional voltage signal using a current to voltage transducer.

The voltage and current signals are then rectified using precision rectifiers to convert them into DC. The rectified voltage and current signals V_{DC} and I_{DC} respectively are fed to two different channels of the multiplexer inputs, which are switched on sequentially by proper commands from the microcomputer. The output of the multiplexer is fed to the A/D converter through a sample and hold circuit. The multiplexer, sample and hold and 8-bit A/D converter form the data acquisition system DAS.

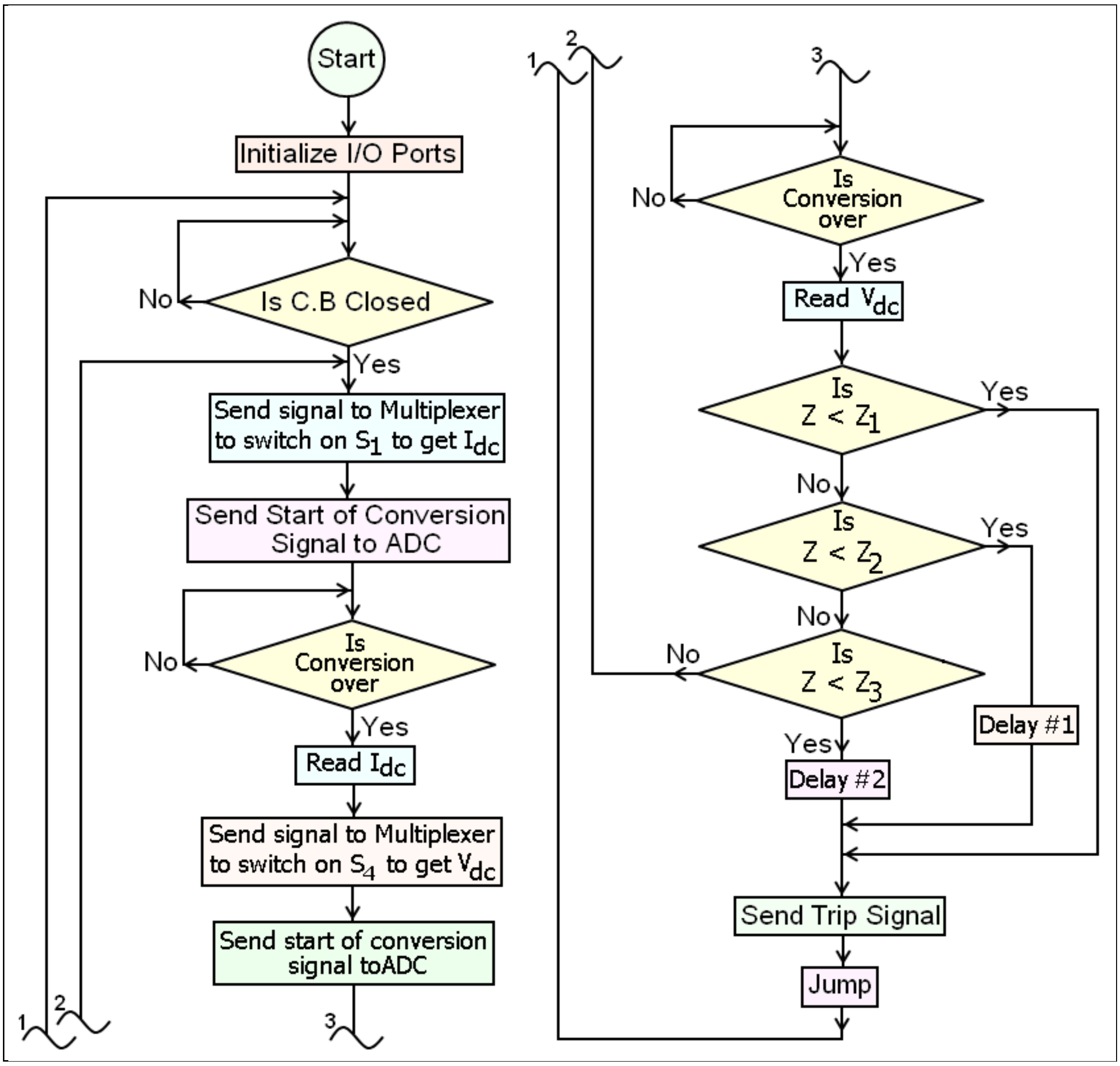


Fig. 3.2-7 Flowchart for Impedance Distance Relay

The data acquisition system DAS is interfaced to the microprocessor using peripheral interfacing adapter PIA. Suitable clock square wave oscillator is used to control the program speed. The controls for analog multiplexer, sample and hold, and ADC are all generated by the microcomputer under program control.

The microcomputer reads V_{dc} and I_{dc} calculates the impedance Z seen by the relay and then compares Z with Z_1, i.e. the predetermined value of impedance for the first zone of protection. If Z is less than Z_1, the microcomputer sends a tripping signal to the trip coil of the circuit breaker instantaneously.

If Z is greater than Z_1, the comparison is made with Z_2, i.e. the value of impedance for the second zone of protection. If Z is less than Z_2, the microcomputer takes up a delay subroutine and sends the trapping signal to the trip coil after a predetermined delay.

If Z is greater than Z_2 but less than Z_3, a greater delay is provided before the tripping signal is sent. If Z is more than Z_3, the microcomputer again reads the voltage and current signals and proceeds according to its program. The program flowchart for the impedance distance relay is as shown in Fig. 3.2-7.

DIRECTIONAL POWER RELAY

A directional relay senses the direction of power flow. The polarity of the instantaneous value of the current at the moment of the voltage peak is examined to decide the direction of power flow. The program developed for this relay is able to decide whether the fault point is in the forward or reverse direction with respect to relay location as in Fig. 3.2-8.

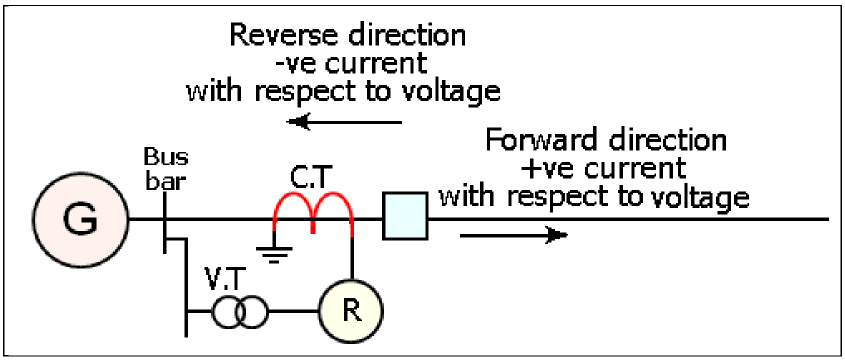


Fig. 3.2-8 Location for Directional Power Relay

Some electromagnetic or static relays are provided with (SPDT) single pole double through switch to control the directionality of the current pass forward or reverse. In the digital relays, this option is found as a software setting. The instantaneous value of the current at the moment of voltage peak is $I_m \cos \Phi$. For a fault point lying in the forward direction $I_m \cos \Phi$ is positive for Φ lying within $\pm 90^o$. For a fault lying in the reverse direction, $I_m \cos \Phi$ becomes negative, as shown in Fig. 3.2-9.

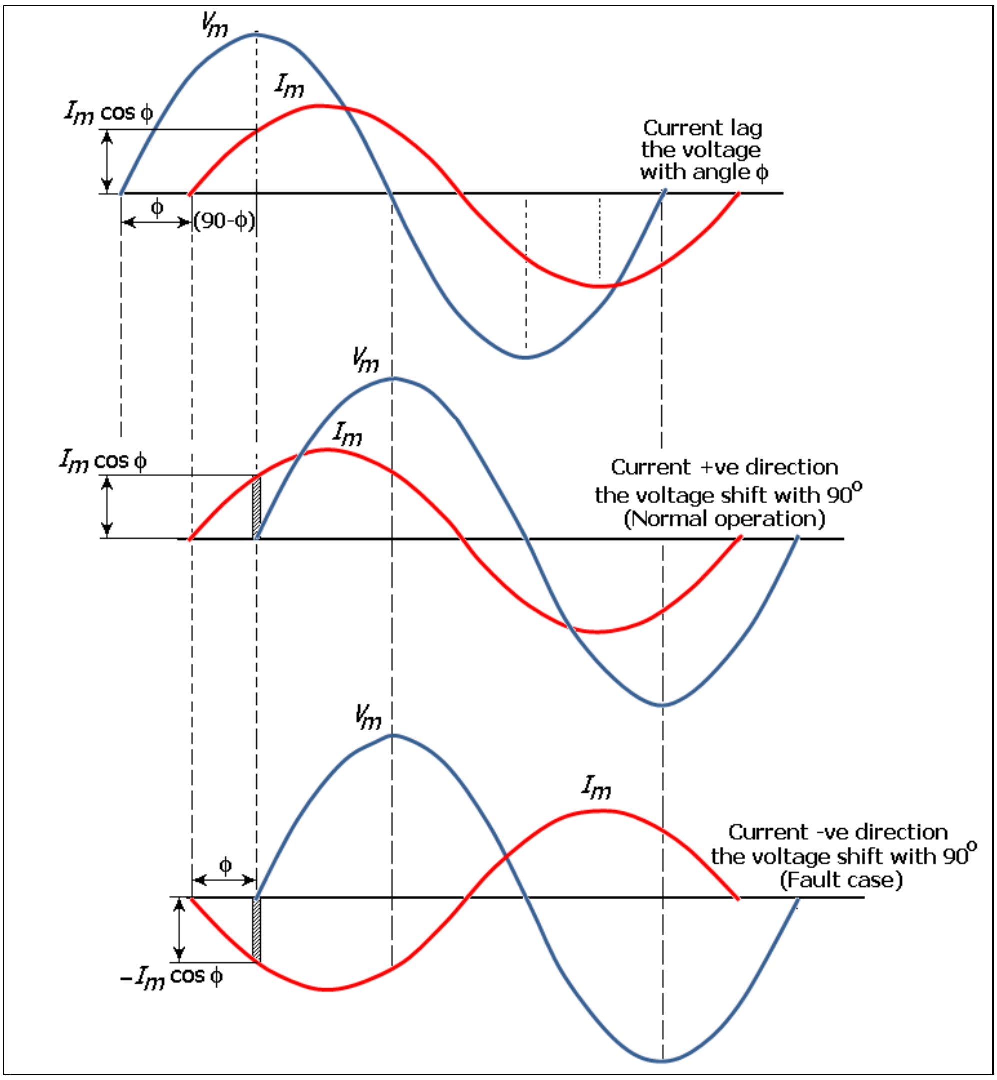


Fig. 3.2-9 Instantaneous Value of Current at Peak Voltage

The block schematic diagram of the interface for this relay is shown in Fig. 3.2-10. A phase-shifter and a zero-crossing detector are used to obtain a pulse at the moment of voltage peak. The voltage signal is fed to the phase-shifter to get a phase-shift of 90^o. Then the output of the phase-shifter is fed to a zero-crossing detector to obtain the

required pulse. The microcomputer reads the output of the zero-crossing detector to examine whether the voltage has crossed its peak value.

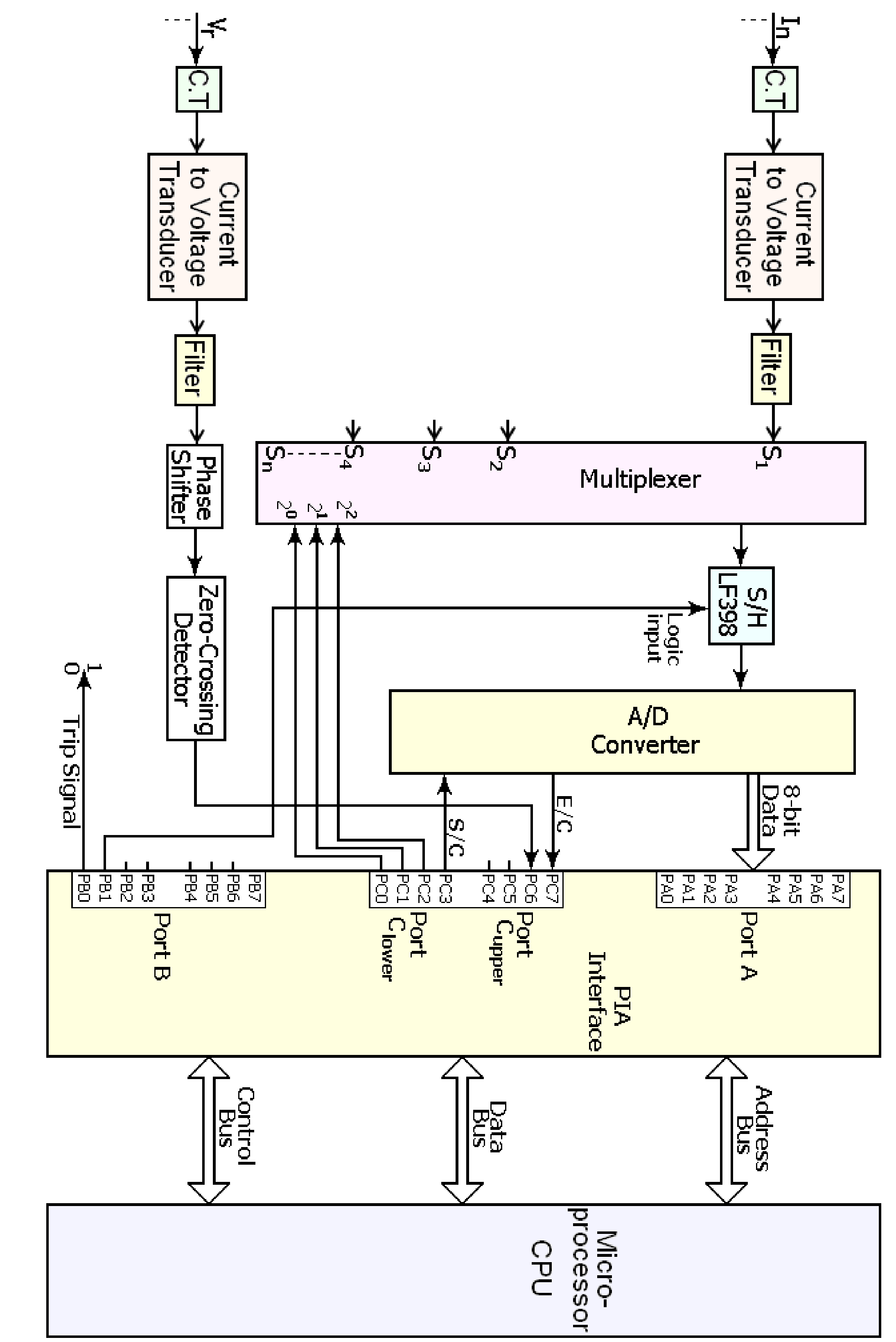


Fig. 3.2-10 Block Diagram for Directional Relay

After receiving the pulse the microcomputer sends a command to the multiplexer to switch on the channel S_2 to obtain the instantaneous value of the current at the moment of voltage peak. The microcomputer reads this value of the current through the A/D converter and examines whether it is positive. This type of relay can be used to sense the reversal of power flow where it is required. When the power flow is reversed, $I_m \cos \Phi$ becomes negative and the microcomputer sends a tripping signal to the circuit breaker. The program flowchart is shown in Fig. 3.2-11.

This relay can also be used in conjunction with overcurrent relays and impedance relays to provide directional features. When it is used as a directional relay, it energizes other relays only when the fault lies in the forward direction. It can also be used as a directional relay in conjunction with overcurrent relays for the protection of parallel lines.

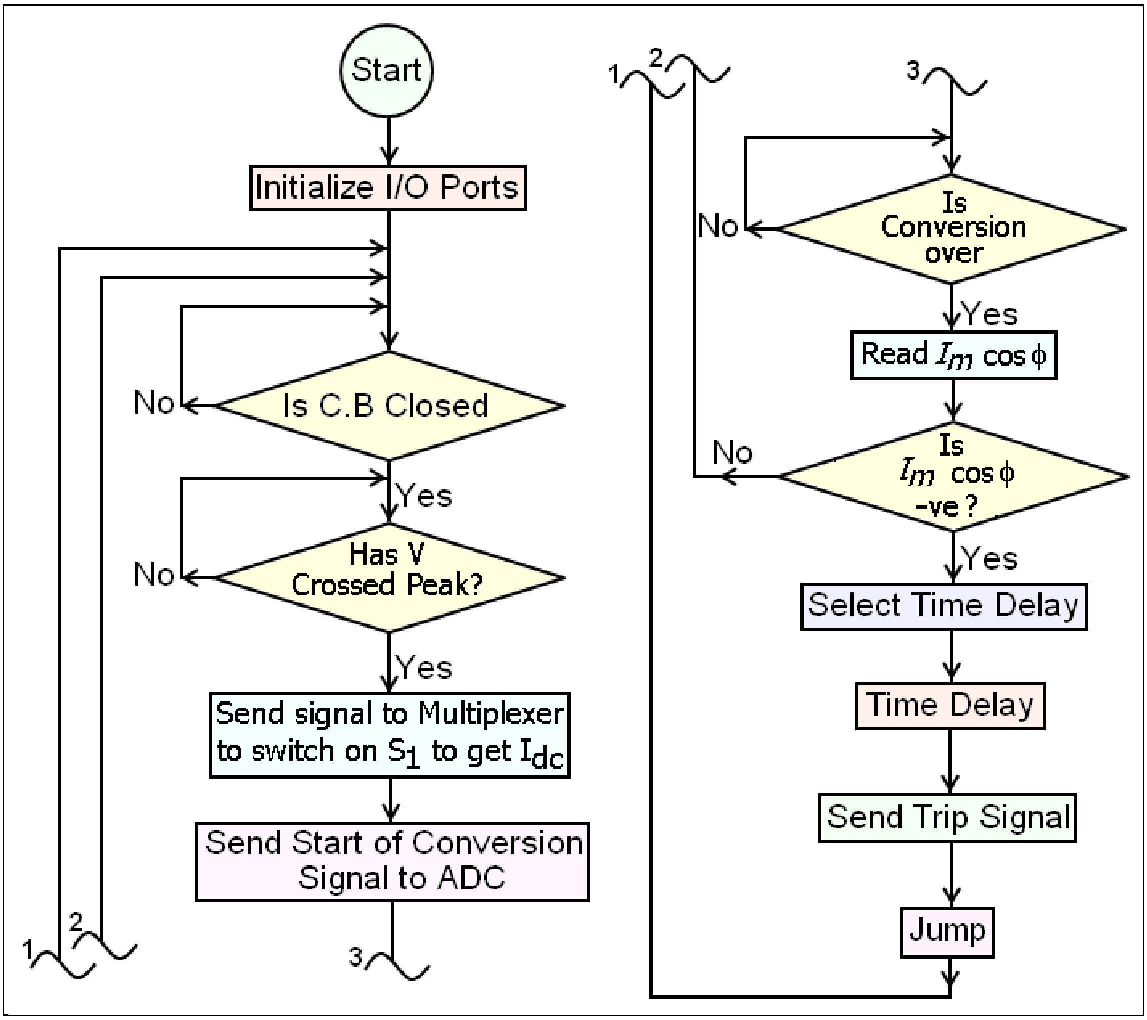


Fig. 3.2-11 Flowchart for Reverse Power Relay

DIRECTIONAL OVERCURRENT RELAY

The directional overcurrent relay incorporates a directional unit, which responds to power flow in a specified direction. The directional relay senses the direction of power flow by means of a phase difference (Φ) between voltage and current. When Φ exceeds a certain predetermined value and the current is above the pick-up value, the directional overcurrent relay operates. The directional relay is a double actuating quantity relay with one input as current from CT and voltage from VT.

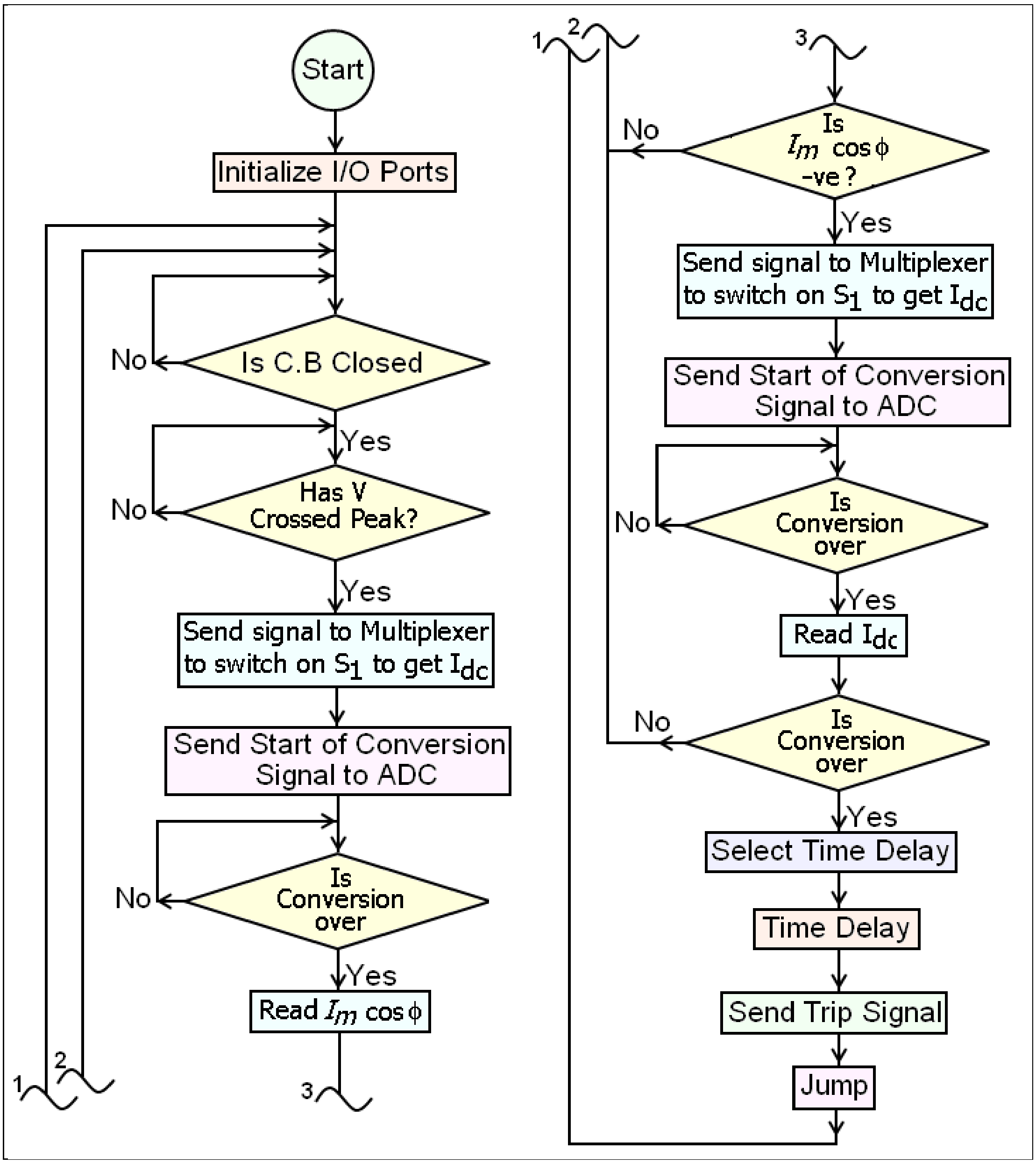


Fig. 3.2-12 Program Flowchart for Directional Overcurrent Relay

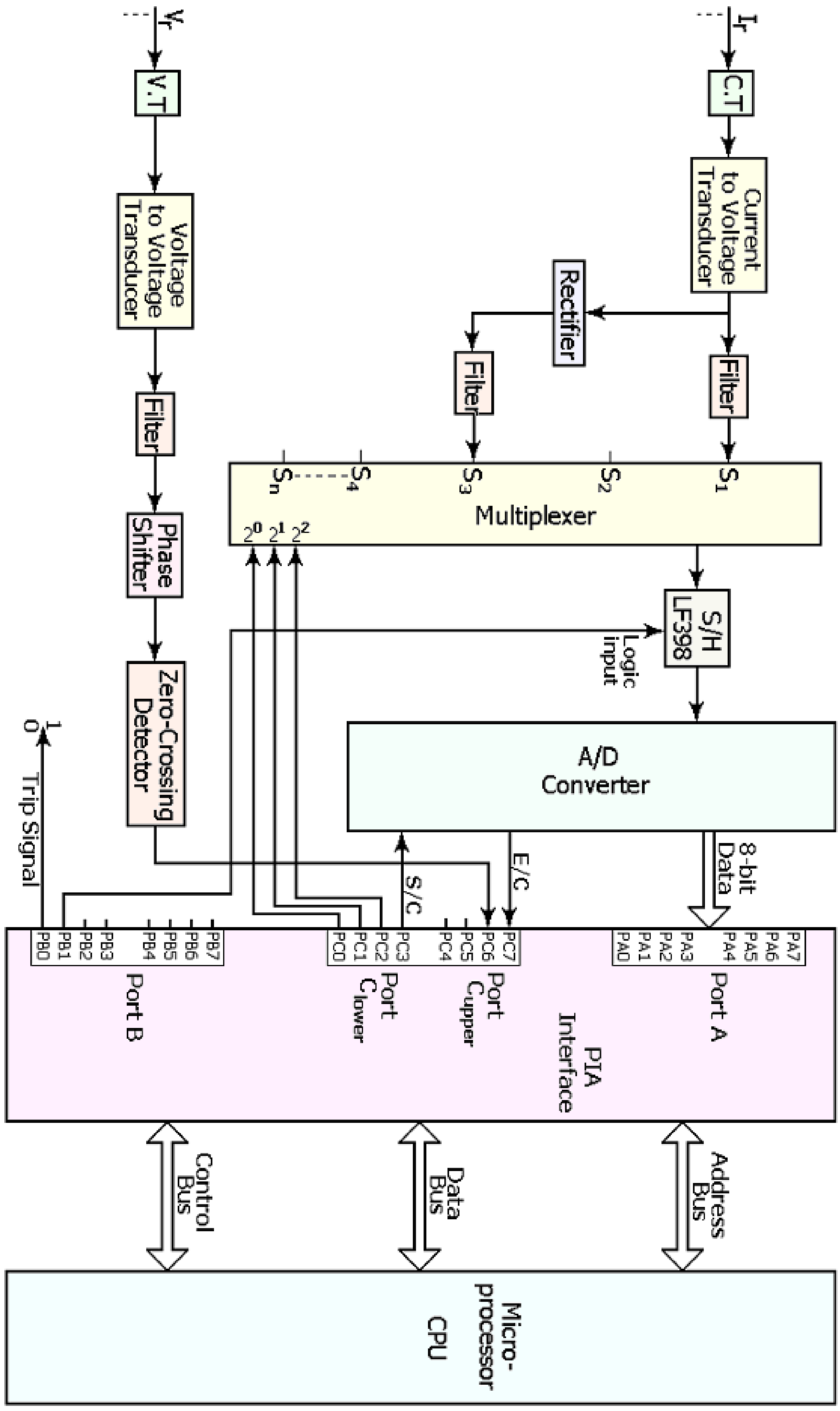


Fig. 3.2-13 Block Diagram for Directional Overcurrent Relay

REACTANCE DISTANCE RELAY

The reactance characteristic is realized by comparing the instantaneous value of the voltage at the moment of current zero against the rectified current. The instantaneous value of voltage at the moment of current zero is ($V_m \sin\varphi$), as shown in Fig. 3.2-14.

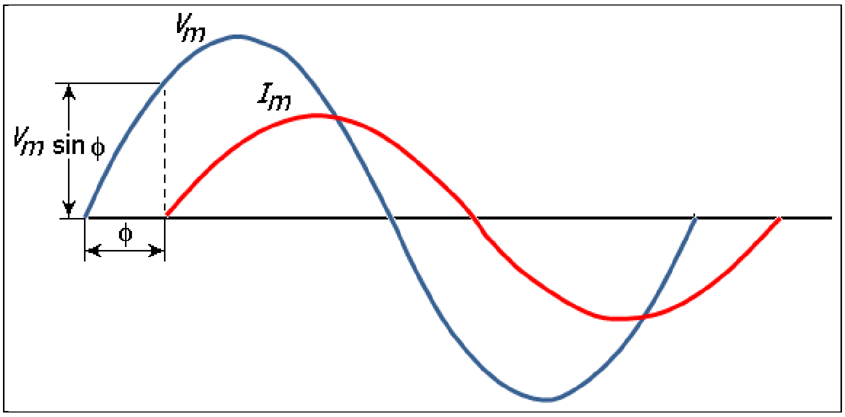


Fig. 3.2-14 Instantaneous Value of Voltage at Zero Current

For the operation of the relay, the condition to be satisfied is as follows.

$$V_m \sin\varphi < K_1 I_{dc} \ or\ V_m \sin\varphi / I_{dc} < K_1$$

Or $$V \sin\varphi / I < K$$

As V_m and I_{dc} are proportional to rms values V and I, respectively.

Then $$Z \sin\varphi < K$$

Or $$X < K$$

The block diagram of the interface for the realization of reactance relay characteristic is shown in Fig. 3.2-15. The microcomputer reads the output of the zero crossing detector to examine whether the current has crossed its zero point.

As soon as the current waveform crosses its zero point, the microcomputer sends a command to the multiplexer to switch on channel S_4, and gets the instantaneous value of the voltage, i.e. $V_m \sin \Phi$ through the A/D converter.

Then the microcomputer sends a command to the multiplexer to switch on the channel S_7 to get the rectified current. Thereafter, the microcomputer calculates X, the reactance as seen by the relay and compares it with X_1, the predetermined value of the reactance for the first zone of protection.

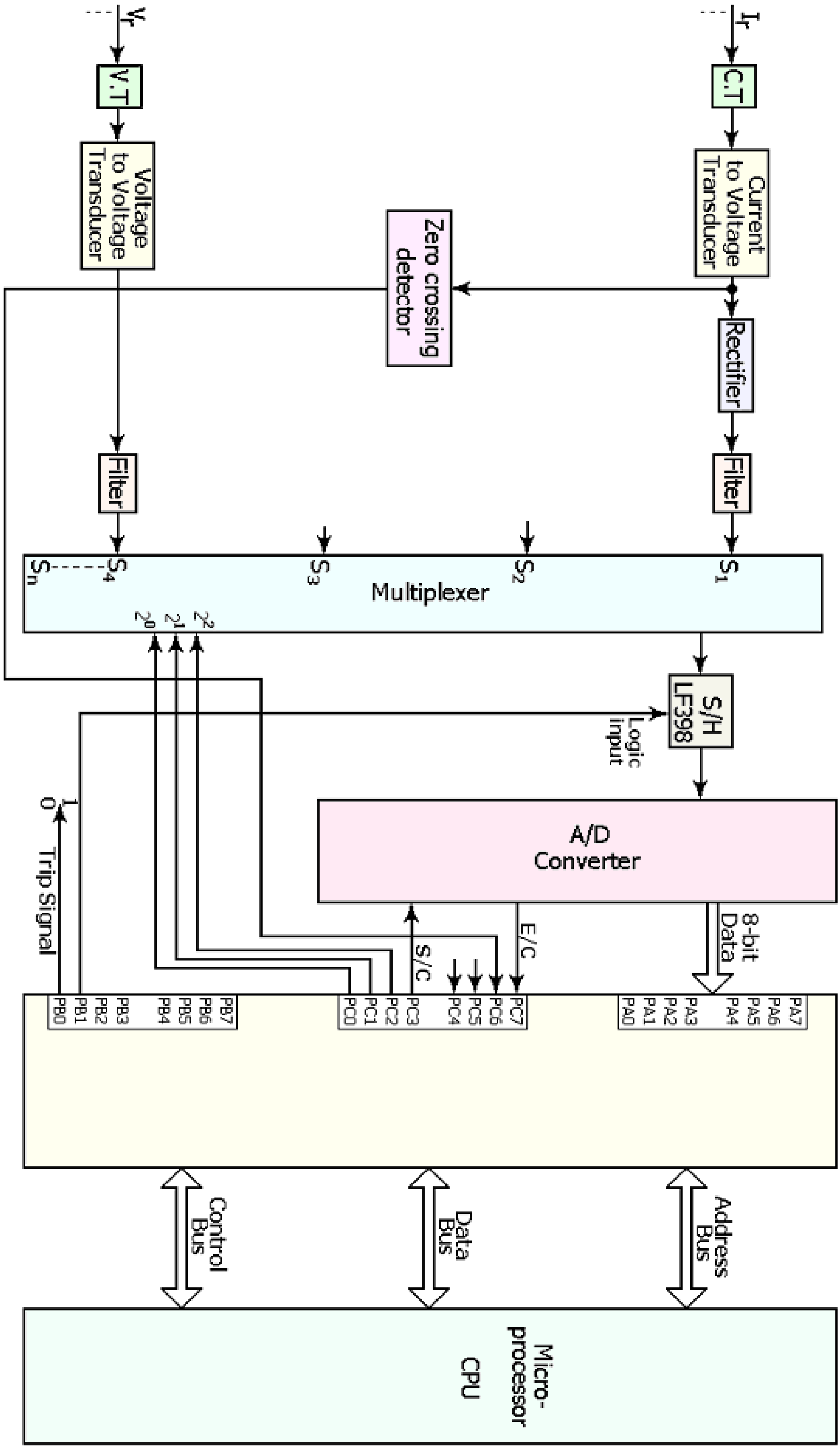


Fig. 3.2-15 Block Diagram of Interfacing Reactance Relay

The microcomputer sends a tripping signal instantaneously, if the measured value of X is less than X_1. If X is greater than X_1, but less than X_2, the tripping signal is sent after a predetermined delay.

If X is more than X_2 but lies within the Protection zone of the directional unit, which also acts as a third, unit as shown in Fig. 3.2-16, the tripping signal is sent after a greater predetermined delay.

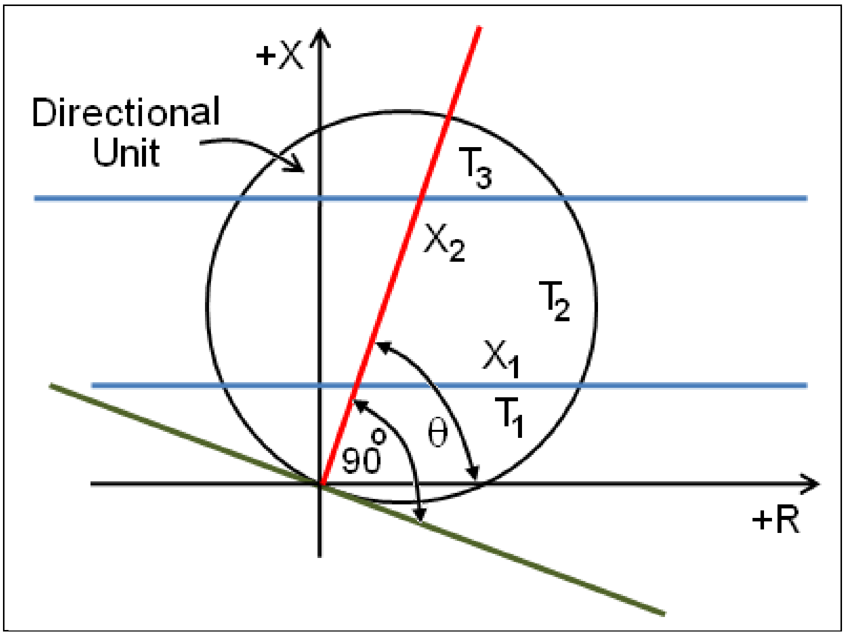


Fig. 3.2-16 Reactance Relay Characteristics with Directional Unit

As the reactance relay is a non-directional relaying unit, a directional relay is used in conjunction with it to provide directional features. The directional unit also serves the purpose of the third unit. The directional unit used for reactance relays has the characteristic of a mho relay passing through the origin. The program of the directional unit is incorporated in the main program of the reactance relaying protective scheme. If the fault point lies within the protection zone of the directional unit then only the reactance relay program is taken up to check the position of the fault point, i.e. whether it lies in the 1^{st}, 2^{nd} or 3^{rd} zone of protection. Depending upon the zone of protection, the tripping signal is sent with or without delay. The program flowchart is as shown in Fig. 3.2-17.

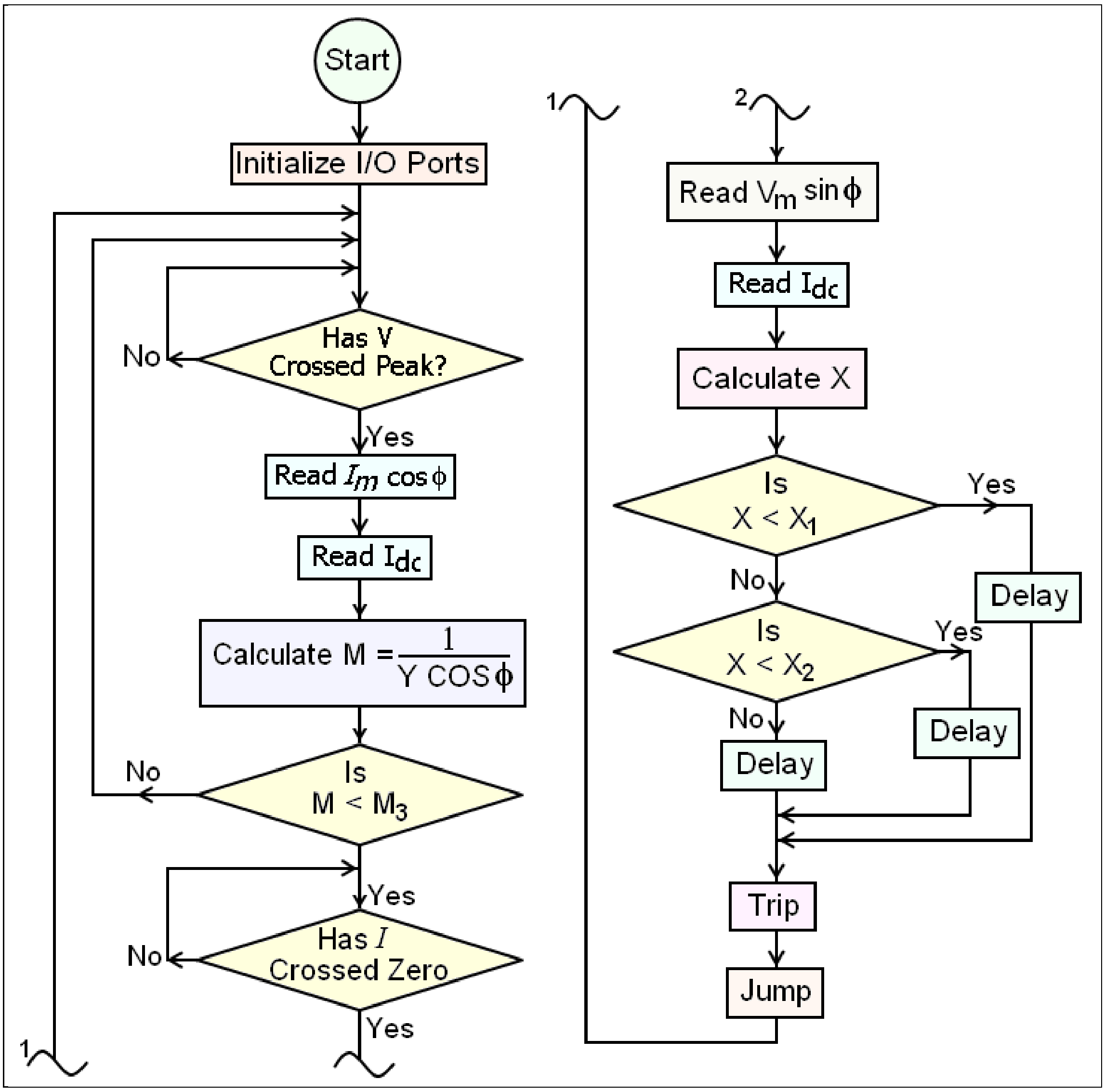


Fig. 3.2-17 Flowchart for Reactance Relay

MEASUREMENT OF R & X

In microprocessor-based distance relaying, the microprocessor calculates the active and reactive components *(R* and X) of the apparent impedance (Z) of the line from the relay location to the fault point from the ratios of the appropriate voltages and currents, and then compares the calculated values of *R* and X to the pickup value of the relay to be realized in order to determine whether the fault occurs within the protective zone of the relay or not. The active and reactive components of the apparent impedance (Z) are resistance (R) and reactance (X), respectively. The algorithm presented in this section for the calculation of R and X assumes that the waveforms of

voltage and current presented to the relay are pure fundamental frequency sinusoids. However, the post-fault voltage and current waveforms fail to be pure fundamental frequency sinusoids due to the presence of harmonics and dc offset components resulting from the fault.

Therefore, analog band-pass filtering of the voltage and current signals is necessary in order to eliminate harmonics and dc offset components and to obtain pure fundamental frequency sinusoidal signals. An active band-pass filter having a band-pass of 40 to 60 Hz is employed to filter harmonics and dc offset. Filtering of harmonics and dc offset from the post-fault voltage and current signals can also be achieved by employing digital filters. A number of digital algorithms, based on the digital filtering technique have been proposed for the calculation of R and X. A few digital algorithms, which are suitable for microprocessor-based protective relaying are discussed in the subsequent sections.

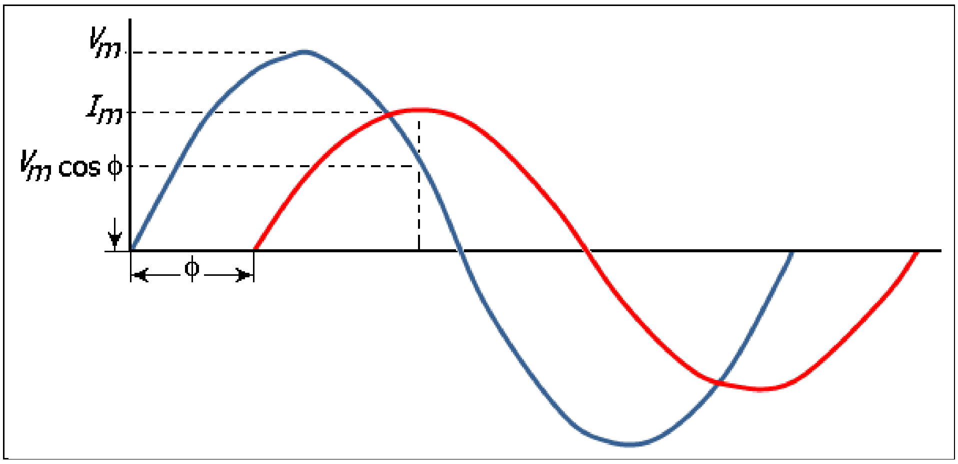


Fig. 3.2-18 Instantaneous value of voltage at the instant of peak current

MEASUREMENT OF RESISTANCE

The resistance as seen by the relay from the relay location to fault point is given by:

$$R = Z\ \cos\phi = (V_m/I_{DC})\cos\phi$$

$V_m \cos \phi$ is the instantaneous value of the voltage at the moment of peak current, as shown in Fig 3.2-18. Therefore, the resistance is proportional to the ratio of voltage at the instant of current peak to the rectified current I_{dc} to obtain a pulse at the moment

of peak current, a phase shifting circuit and a zero-crossing detector have been used. The current signal is fed to the phase shifter to get a phase shift of 90^o. Then the output of the phase shifter is fed to the zero crossing detector, as shown in Fig. 3.2-19 to obtain the required pulse.

The microcomputer reads the output of the zero-crossing detector, in order to examine whether the current signal has reached its peak. As soon as the current crosses its peak, the microcomputer sends a command to the multiplexer to switch on channel S_4 to obtain the instantaneous value of the voltage at the moment of peak current, which is equal to $V_m \cos\phi$.

The microcomputer reads this instantaneous value of the voltage through the A/D converter, and stores the digital voltage value in the memory. The current signal is converted to dc using a precision rectifier. The microcomputer gets the rectified dc current through the multiplexer channel S_7 and A/D converter. After getting the values of $V_m \cos\phi$ & I_{DC} the microcomputer calculates the value of resistance.

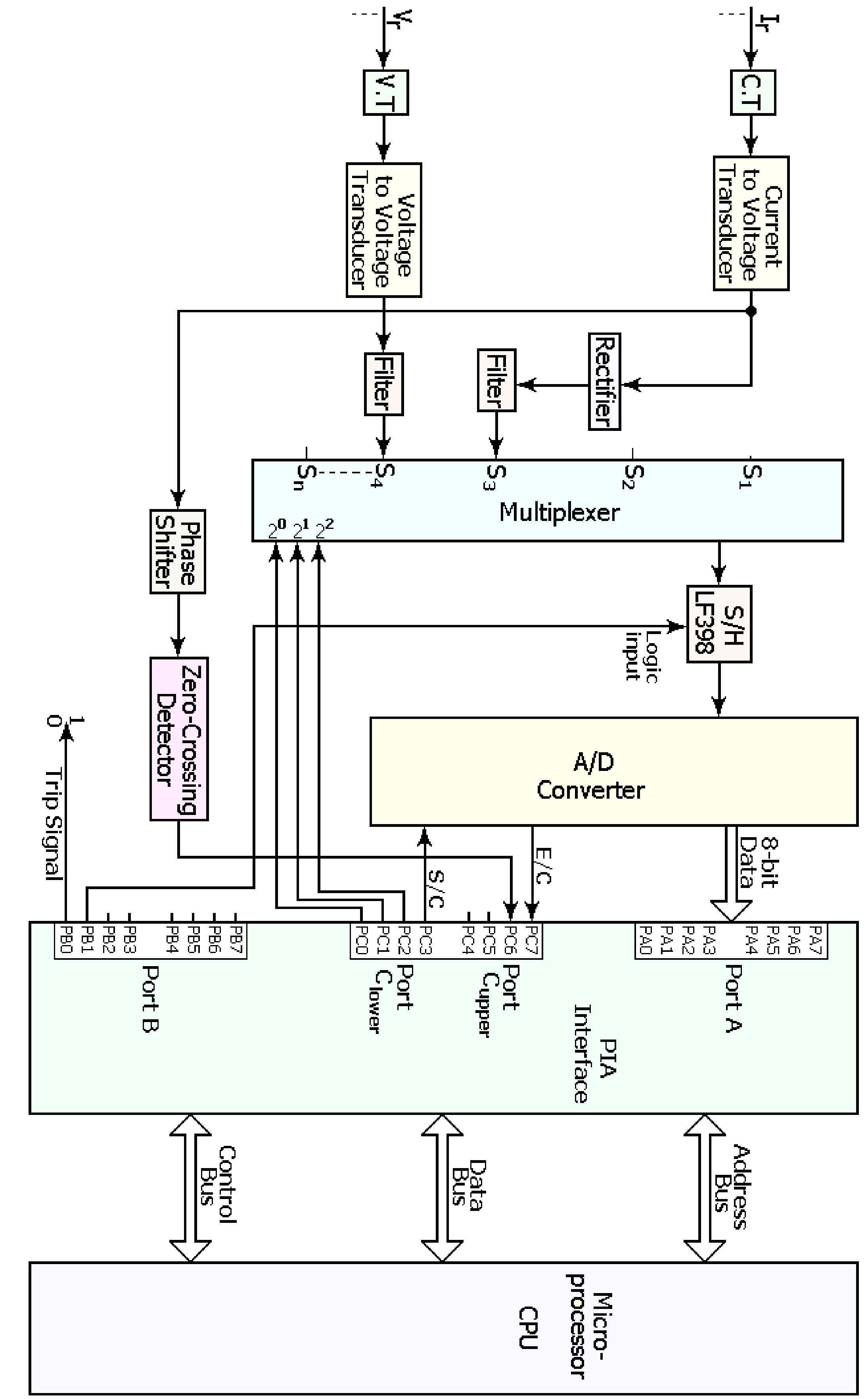


Fig. 3.2-19 Block Diagram of Interfacing Resistance Measurement

MEASUREMENT OF REACTANCE

The reactance seen by the relay is given by:

$$X = Z \ \sin\phi = (V_{AC}/I_{DC})\sin\phi$$

The instantaneous value of the voltage at the moment of zero current is $V_m \ \sin\phi$ as shown in Fig. 3.2-14. Therefore, the reactance is proportional to the ratio of voltage at the moment of current zero to the rectified current. The interface for the measurement of reactance will be the same as that for the reactance relay, as shown in Fig. 3.2-20.

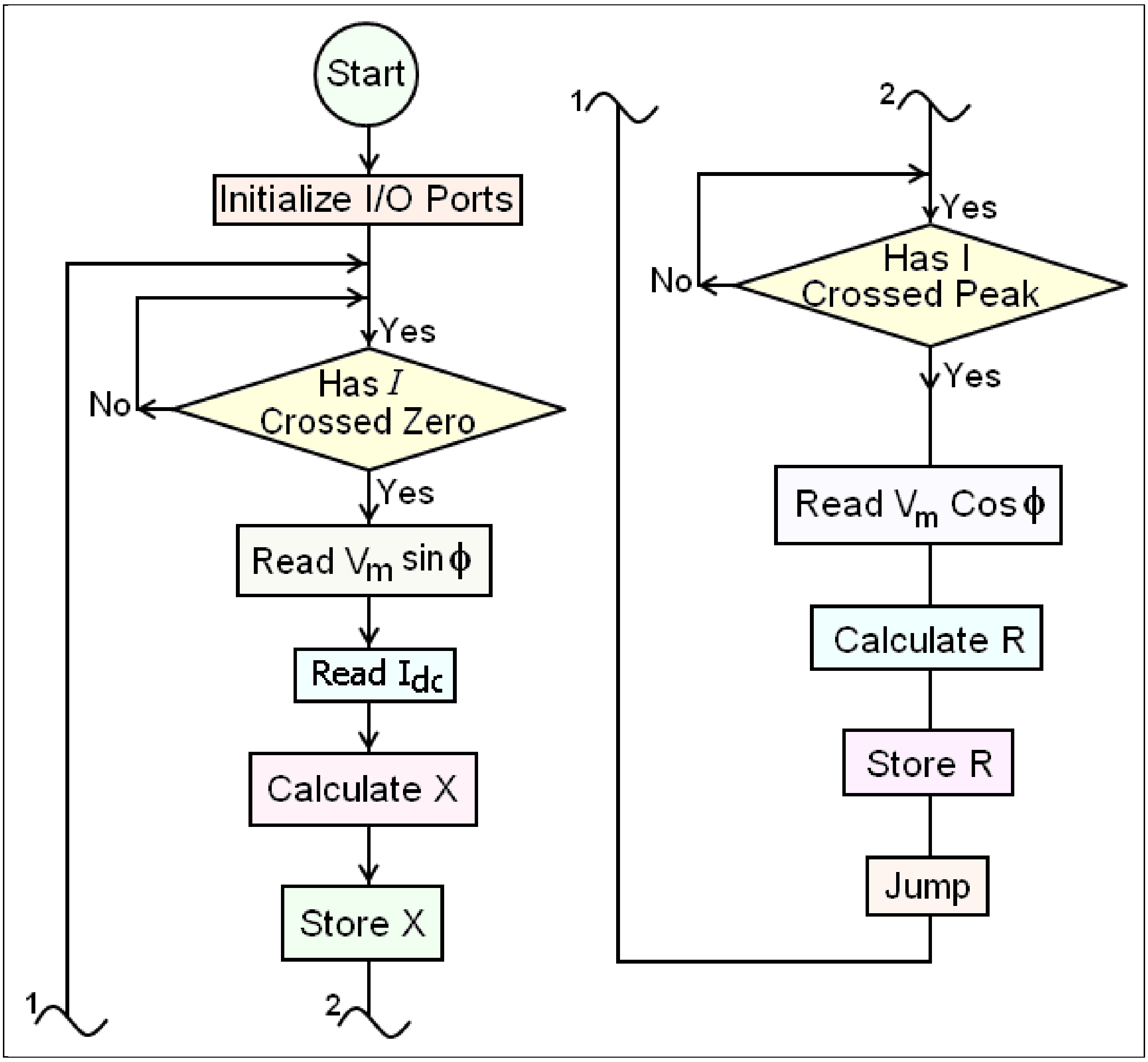


Fig. 3.2-20 Flowchart for Measurement of R & X

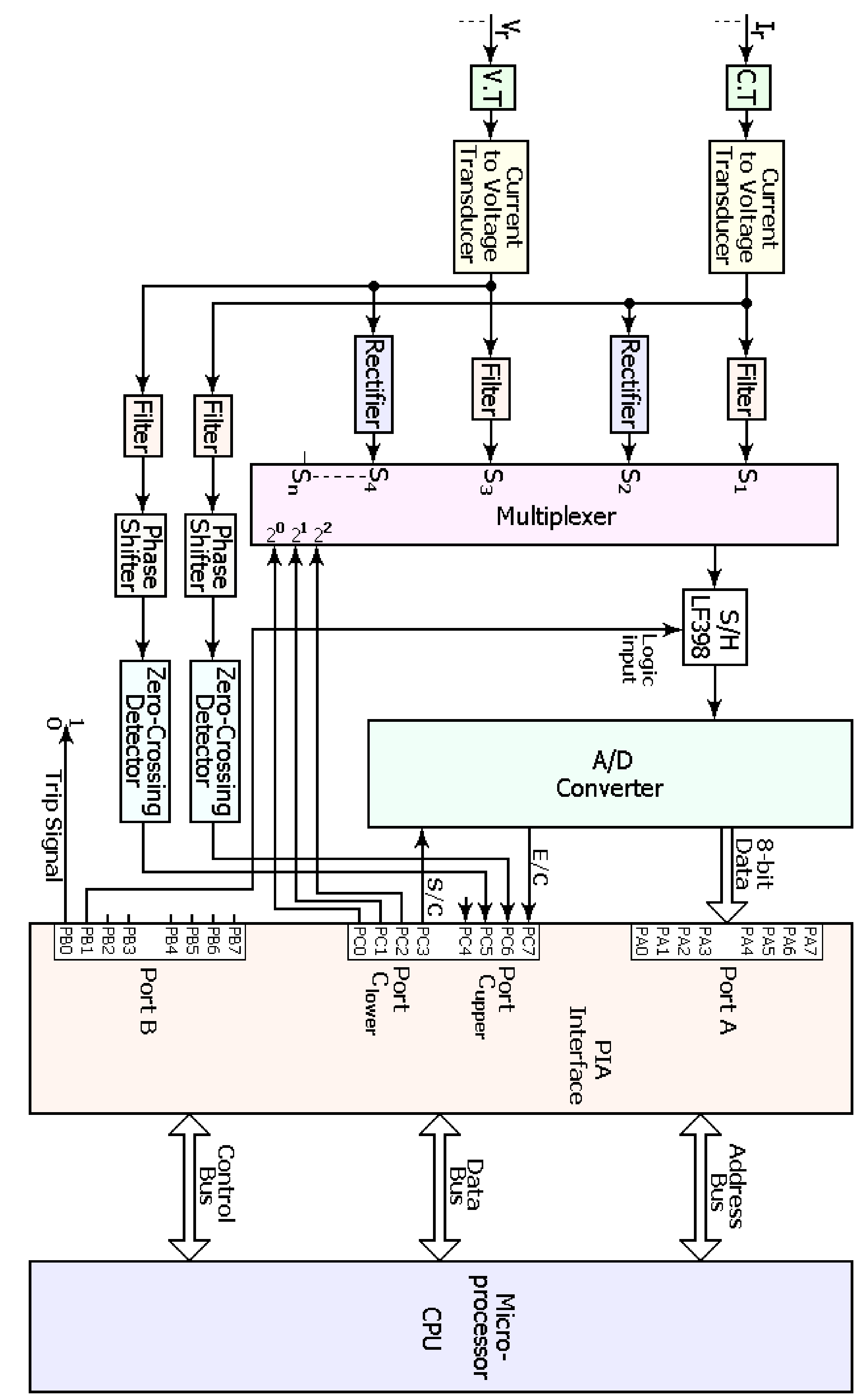


Fig. 3.2-21 Block Diagram of General Interface of Distance Relay

The microcomputer reads the output of the zero-crossing detector and examines whether the current has reached its zero instant. As soon as the current crosses its zero, the microcomputer reads the instantaneous value of the voltage through the multiplexer channel S_4 and A/D converter. Then the microcomputer reads the rectified current I_{dc} through the multiplexer channel S_4 and A/D converter. After receiving the values of $V_m \sin \Phi$ and I_{dc} the microcomputer computes the reactance X.

MULTI-FUNCTION NUMERICAL RELAYS

The multi-function numerical relays are the recent versions of digital relays. Nearly the same hardware and the basic elements are found in the multi-function relays. The difference between them and the last generation of digital relays are in the microprocessor, which is replaced with microcontroller, it has higher frequencies and double processing operation, and also it has much more software to be able to handle any protection scheme. You can find multiple choices to select the required options among the relay settings.

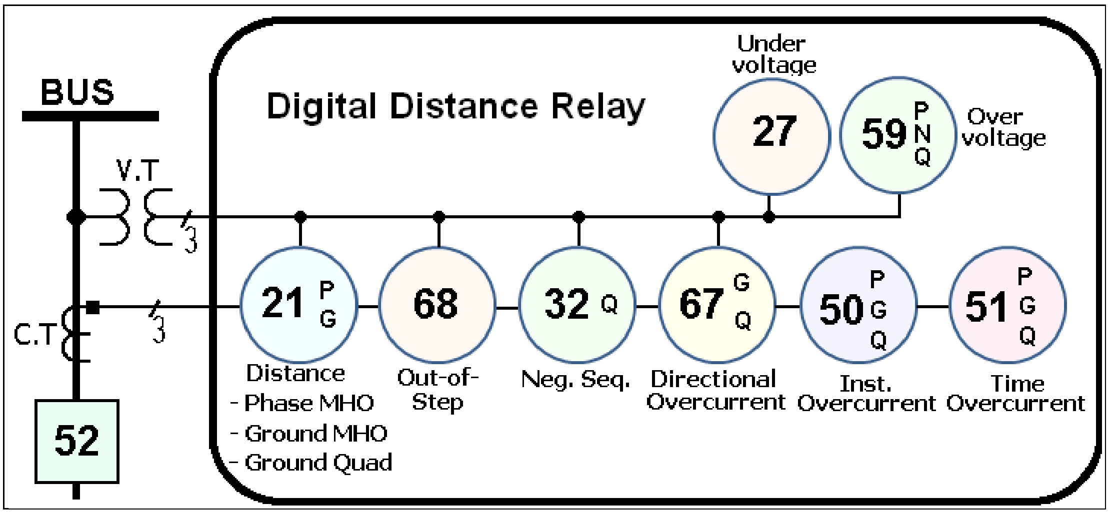


Fig. 3.2-22 Basic Functions of Digital Distance Relay SEL-321

An example for a numerical distance relay is shown in Fig. 3.2-22. In this relay a great number of relay schemes like time overcurrent, overvoltage, under voltage, out of step, negative sequence, and directional overcurrent relay are included in the same

relay package. The user can enable or disable any of these functions and put the required setting for them as the protective power system needs.

Another example is shown in Fig. 3.2-23 for a numerical distance relay SEL311. It has some differences in the number of structure elements. It has synchronism check and auto recloser more than the last relay of Fig. 3.2-22.

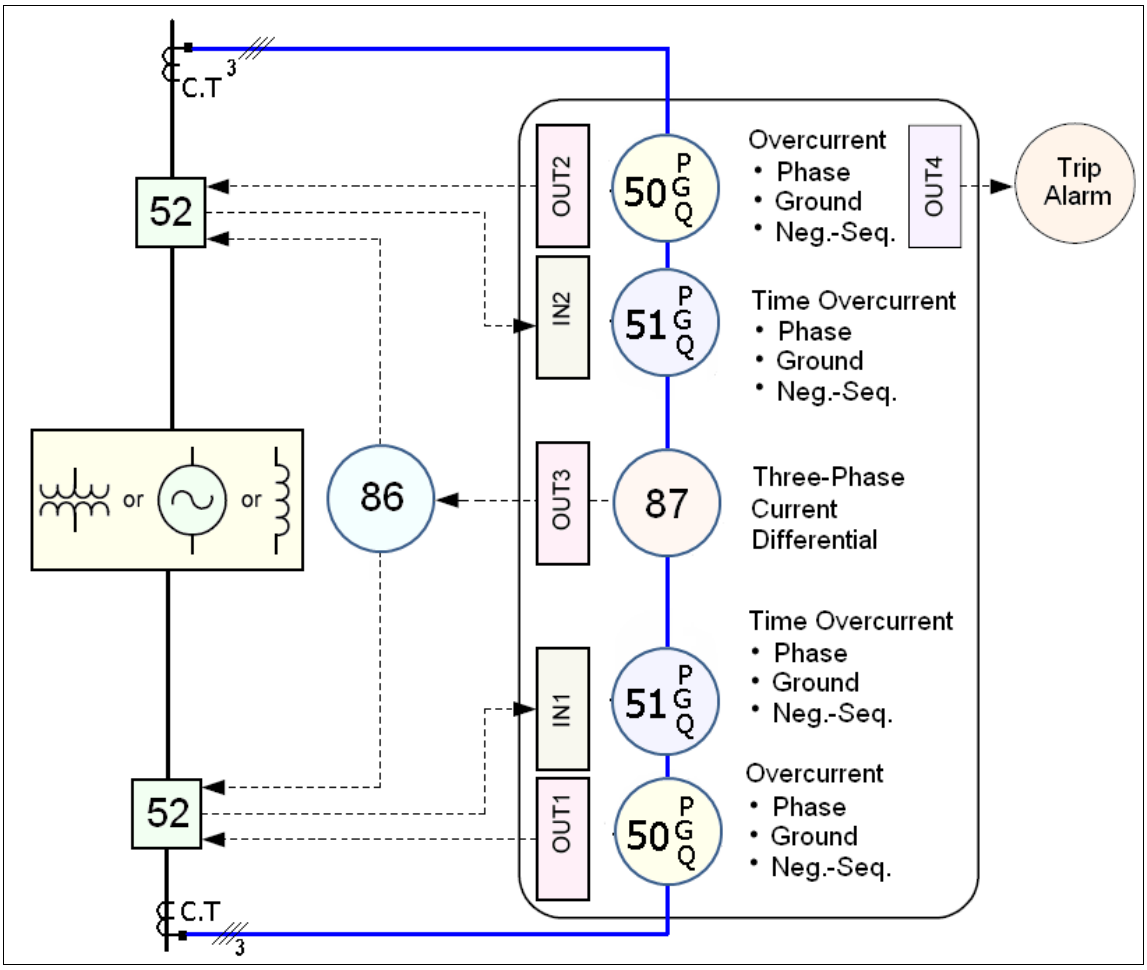


Fig. 3.2-23 Basic functions of digital Differential relay SEL-587

From the features of numerical multi function relays, it is to program the output contacts to produce signals to conduct with any external hardware like sending trip signal to circuit breakers, sending signal to record certain event in the fault recorder, send communication data to SCADA system, or communicate with RTU system, or any other device.

Another feature is to get the relay work as complete instrument measurement panel to measure current, voltage, power, frequency, vars, and any other measurements.

SUMMARY

- Flowchart diagram consists of some components:
  1. Start
  2. End
  3. Read
  4. Process
  5. Condition
- Digital timers are widely used to coordinate the backup protection and control the relay internal processes.
- Time delay of the digital relay can be set from definite time (given to the relay setting) or from lookup table (stored in the relay memory).
- The idea of the impedance relay is to measure input voltage and current, then compute $Z = {}^{V}\!/\!_{I}$ for each phase.
- The current phase angle is determined by measuring the time between zero crossing for each of the voltage and current, then converting that time to degrees.
- The idea of reversing power directional relay is to study the sign of current signal (+ve or -ve) at the moment of V_m after shifting the voltage with 90^o.
- The idea of digital reactance distance relay is to measure the instantaneous value of voltage at the moment of current zero, dividing that voltage by the rectified current I_{dc}, $X = {}^{(V_m \ \sin\varphi)}\!/\!_{I_{dc}}$
- The multi-function numerical relay can be set to many protection schemes, according to the types of inputs.
- The multi-function relay is programmed to all or some of its options.

GLOSSARY

Hardware:	The integrated or discrete components of the relay
Flowchart:	The software diagram of the relay program
Block diagram:	A type of illustration with undetailed for the internal operation
Condition instruction:	A test instruction from the program to select one of two conditions.
Data acquisition:	Information data collection and organize it.
Predetermined value:	The applied setting value.
Multi-function:	The different features in an application.
SCADA:	Supervisory control and data acquisition system.

REVIEW EXERCISE

1. What is the function of current transducer in the digital relays?

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   ………………………………………………………………………………………
2. What is the function of voltage transducer in the digital relays?

   ………………………………………………………………………………………

   ………………………………………………………………………………………
3. How can a digital relay prevent the false tripping?

   ………………………………………………………………………………………

   ………………………………………………………………………………………
4. What is the function of AC filter?

   ………………………………………………………………………………………

   ………………………………………………………………………………………
5. What is the function of phase shifter in the directional relays?

   ………………………………………………………………………………………

   ………………………………………………………………………………………
6. What is the function of S/C terminal in the hardware of the digital relays?

   ………………………………………………………………………………………

   ………………………………………………………………………………………
7. What is the function of control bus terminals (S_o, S_1,S_2, …) to the multiplexer?

   ………………………………………………………………………………………

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8. What is the function of jump process in the flowchart?

   ………………………………………………………………………………………

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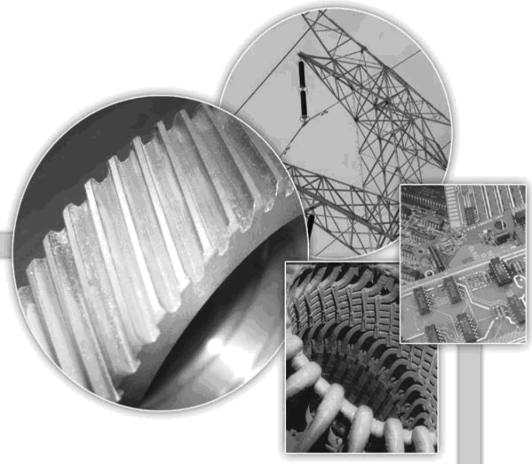


LESSON 3.3

DIGITAL RELAY APPLICATIONS

LESSON 3.3
DIGITAL RELAY APPLICATIONS

OVERVIEW

This lesson describes in detail all the tests, which must be performed on the digital relay, whatever its type or manufacturer. The lesson scopes out how to test relay elements, creating setting file and configuration file, applying complete test using secondary injection test set, retrieving the stored information from the relay, and checking the disturbance record to analyze the events.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Implement the installation of the digital relay.
- Install the relay software on the PC.
- Create and load setting file of the digital relay and restore it from the relay.
- Retrieve the stored information of the relay.
- Perform the complete testing procedure of the relay.
- Restoring the disturbance record file to analyze the events.

INTRODUCTION

The digital relay applications, which act a part of the relay technician duties is similar to that of the electromechanical and static relays, except some variations between them. The following operations are responded from the relay technician:

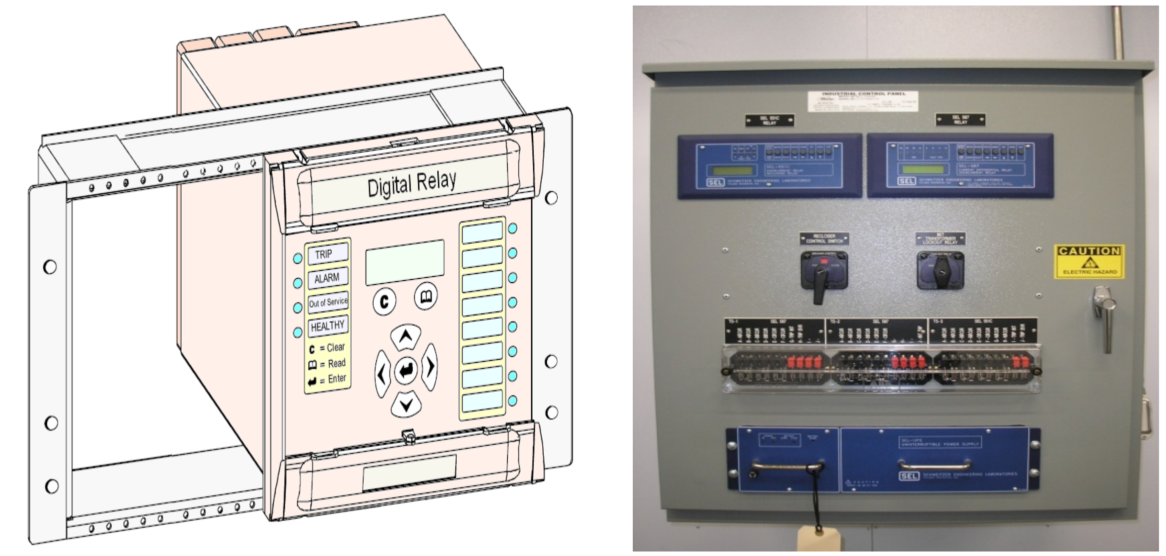
- Installation for digital relays.
- Setting the relay.
- Testing the relay.
- Reporting the relay.

INSTALLATION FOR DIGITAL RELAY

The installation of the digital relay, means preparing the requirements to fix, connect, initialize, and energize the relay in its final place in the site of work.

RELAY INSTALLATION REQUIREMENTS

The requirements of the relay include the relay mounting on either rack or panel according to the recommendation of the relay manufacturing as shown in Fig. 3.3-1.



(a) Rack Mounting (b) Panel Mounting

Fig. 3.3-1 Digital Relay Mounting

The requirements also include the wires, cables, and plugs which needed to verify entering current, voltage, logic, and communication inputs and to produce output trip commands and retrieve the relay information.

RELAY CONNECTION

The installation work of the relay is to connect the wiring of inputs and outputs, each wire in its correct terminal at the rear side of the relay. Because a large number of wires are used with the relay terminals, it is better to use color wires and labels to define each wire.

Note, the current wires differ from voltage and communication wires. Some digital relays have facility to operate with CT secondary either 1A or 5A, the technician's just select the suitable terminals to connect. This selection leads to another selection in the setting file, which will discuss later. The technicians should take care the system phase sequence must agrees with relay phases. The ground terminals of the CT and VT secondary must be connected to their suitable places. The digital relay connection of Fig. 3.3-2 shows four logic inputs.

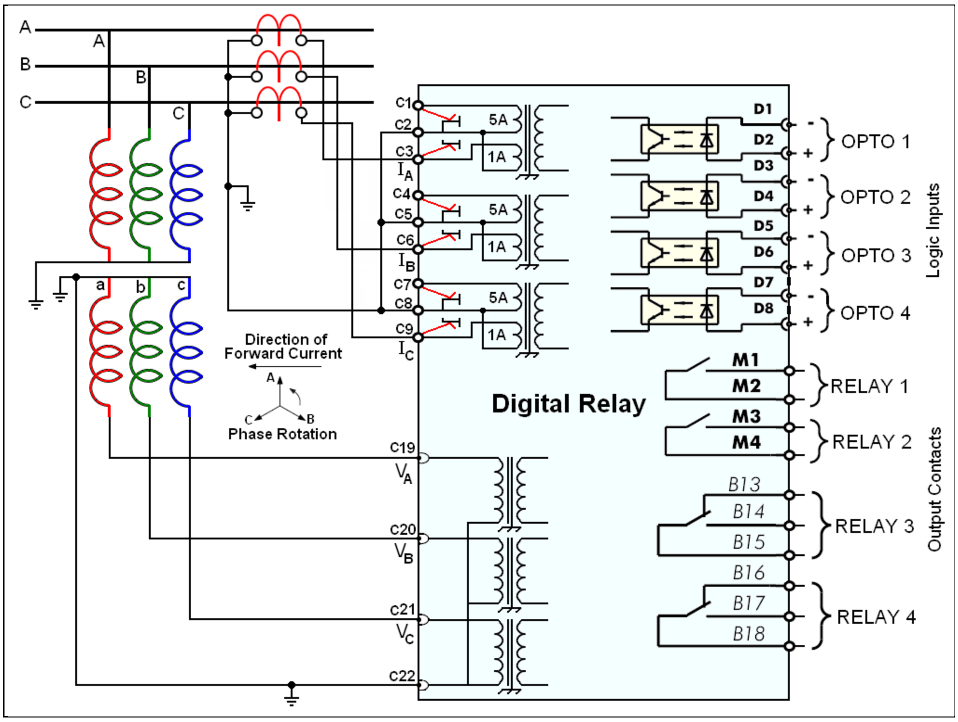


Fig. 3.3-2 Schematic Diagram for Digital Relay Connections

Some relays have a lot of these logic inputs. This relay also shows four output contacts, two of them normally open and the other two are normally closed, some relays have many of these numbers depending on the relay specifications.

In the digital distance relay, the relay should contains 3-phase input current and 3-phase input voltage terminals as the relay of Fig. 3.3-2, while in differential relay, the relay should contains 6-phase input current and no voltage is needed.

Another applications need voltage only or current only depending on the protection scheme. Anyway, any input/output terminals should be defined to the relay in the hardware by connection and labels, and on the software in the relay setting and configuration files.

The relay wiring should contain suitable terminals according to the relay terminal block and fix them carefully with screwdriver. Variety of terminals is shown in Fig. 3.3-3. The wire terminals are chosen according to the wire types and size.

Fig. 3.3-3 Different Types of Relay Wiring Terminals

The other side of wiring is connected to a terminal block on the relay panel or extended to the instrument transformers, breaker control circuits, or data networks.

SOFTWARE REQUIREMENTS

The software requirements are to available PC or laptop and data cables to connect with the relay during applying the setting or testing the relay. The data cable plugs are needed to communicate the digital relay with the PC or LANs (local area networks). There are many types of data cable plugs, some of them are shown in Fig. 3.3-4.

(a) RS232 (b) RS485 (c) RJ45

Fig. 3.3-4 Digital Relay Cable plugs

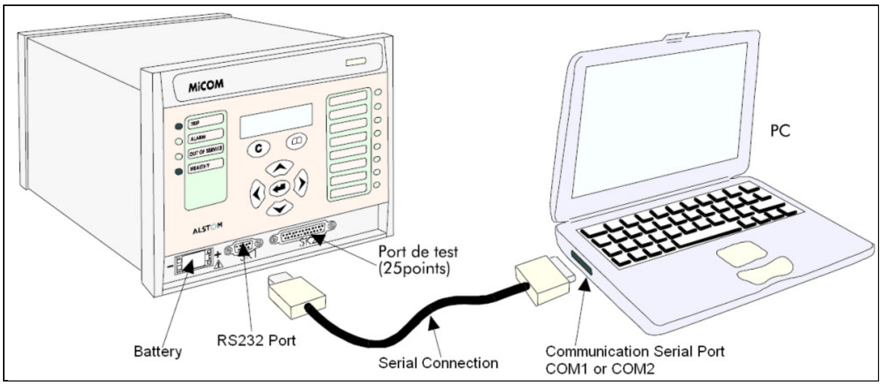


Fig. 3.3-5 Connection between Computer & Digital Relay

A desktop or laptop computer is needed to verify entering, retrieving data, or applying test procedure to the digital relay with the following specifications:

- IBM PC or 100 % compatible
- Compatible Windows for the user program
- Suitable processor for fast achievement of the task operation
- Suitable screen card with high resolution
- Suitable amount of Gega Bit RAM at least
- Suitable free memory space on PC hard disk

INSTALLING RELAY SOFTWARE

1. To install the relay software on the PC you must first uninstall the previous copy of software to avoid any conflict with the program operation.
2. Insert the CD ROM of the relay software in the PC
3. The program set-up is run automatically
4. Choose the installation language and follow the instructions until it finished.

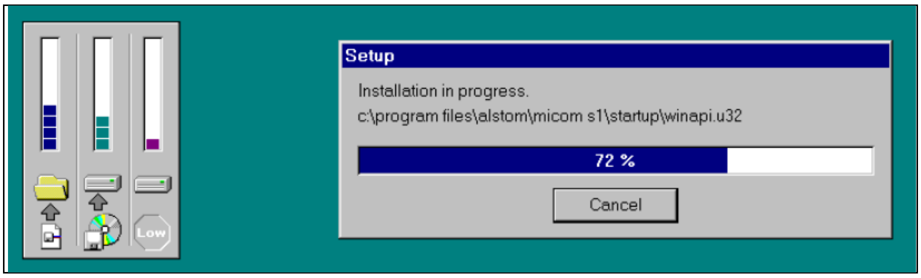


Fig. 3.3-6 Relay Software during Installing

5. Restart the computer to complete your installation, this operation may be postponed but until it has been done you cannot run the program.
6. Launch the program to browse the software facilities, you should get some options in an icon form, as shown in Fig. 3.3-7.

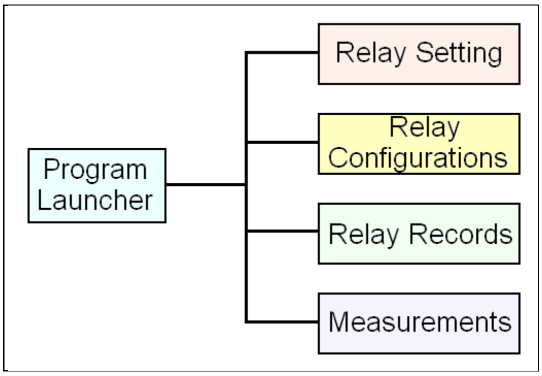


Fig. 3.3-7 Software Facilities of Digital Relays

Each icon opens a file, the important two files are:

- Relay Setting File
- Configuration file, sometimes called (PSL) Programmable Scheme Logic file

RELAY SETTING FILE

Click on the relay setting icon, the setting file opens, you should get the relay default setting, it is ready to edit and change the contents with the real setting, which is given to the relay technician to download it to the relay. The setting file can be fill in on the PC and saved outside the relay, then transfer it to the relay using certain connection. Recovering setting file from the relay can also be done through the PC. Some digital relays accept two groups of setting and one of them must activate.

The setting file should include the following items:

- System information
- System parameters
- Date & time
- CT & VT ratios
- Setting groups (if found)
- Programming timers
- Programming LEDs
- Programming logic inputs
- Programming output contacts
- Auto-recloser setting

Each item of the last menu opens a dialog with some properties, which differ from relay manufacture to another.

COMMISSIONING OF DIGITAL RELAYS

To commission digital relays, it is only necessary to verify that the hardware is functioning correctly and the application-specific software settings have been applied to the relay. It is considered unnecessary to test every function of the relay if the settings have been verified, because the relay is fully numerical in their design and implementing all protection and non-protection functions by its software.

VISUAL INSPECTION

Carefully examine the relay against physical damage has occurred since installation. The rating information given on the relay front cover should be checked to ensure it is

correct for the particular installation. Ensure that the case earthing connections are used to connect the relay to a local earth bar using an enough conductor.

CT SHORTING CONTACTS

If required, the current transformer shorting contacts can be checked to ensure that they close when the terminal block is disconnected from the current input.

INSULATION

Isolate all wiring from the earth and test the insulation with an electronic tester at a dc voltage not exceeding 500V. Terminals of the same circuits should be temporarily connected together.

The main groups of relay terminals are:

1. CT & VT circuits
2. Auxiliary voltage supply
3. Opto-isolated control inputs
4. Relay contacts
5. Communication ports
6. Case earth

The insulation resistance should be greater than 100MΩ at 500V. On completion of the insulation resistance tests, ensure all wiring is correctly reconnected to the relay.

LIGHT EMITTING DIODES (LEDS)

On power up the green LED should have illuminated and stayed on indicating that the relay is healthy. Some digital relays have programmable LEDs, these LEDs can be tested through software facility or from an auxiliary supply. If any of these LEDs are on then they should be reset before proceeding with further testing. If the LEDs successfully reset (the LED goes out), there is no testing required for that LED because it is known to be operational.

INPUT OPTO-ISOLATORS

This test checks that all the opto-isolated inputs are functioning correctly. Each digital relay should have number of opto-isolated inputs, which differs from relay to another.

The opto-isolated inputs should be energized one at a time. Ensuring correct polarity, connect the field supply voltage to the appropriate terminals for the input being tested. The opto-isolated input terminal allocations should be given first.
The opto-isolated inputs are energized from an external 50V battery in some installations. Check this case before connecting the external voltage otherwise, damage to the relay may result. The status of each opto-isolated input can be viewed, a ‘1’ indicating an energized input and a ‘0’ indicating a de-energized input. A simple schematic circuit to test opto-isolators is shown in Fig. 3.3-9.

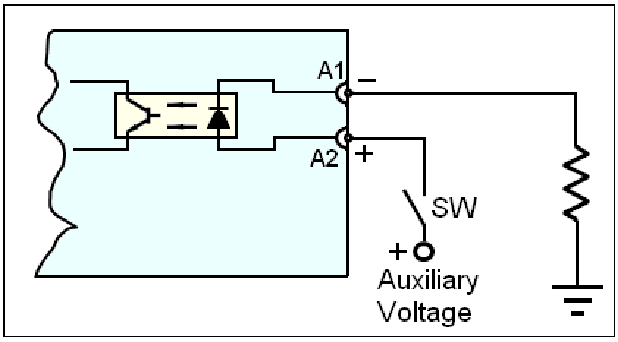


Fig. 3.3-8 Testing an Opto-Isolator

OUTPUT RELAYS

This test checks that all the opto-isolated inputs are functioning correctly. Each digital relay should have number of output relays, which differs from relay to another. Ensure that the relay is still in test mode. Connect continuity tester across the terminals of the output relay 1.

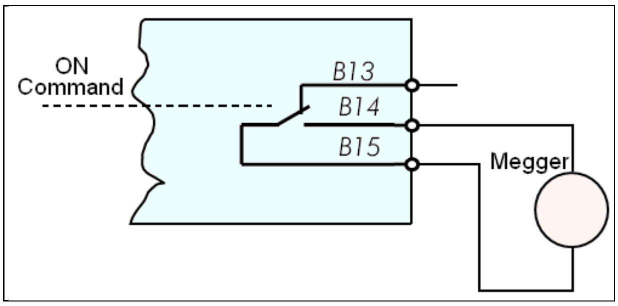


Fig. 3.3-9 Testing an Output relay by continuity Test

Send an ON command, operation will be confirmed by the continuity tester operating for a normally open contact and ceasing to operate for a normally closed contact. Reset the output relay by removing the ON command. Repeat the test for the other output relays. A simple schematic circuit to test output contacts for continuity is shown in Fig. 3.3-9.

COMMUNICATION TEST

The communication links between relay and computer and between relay and network. The communication with PC is verified through the relay software from the computer, this step is important before inserting setting file or retrieving data from the relay.

The other type of communication can be tested through digital tester and RJ45 network cable, depending on the communication protocol of the relay. Some relays sometimes need a communication converter (modem) to convert from protocol to another or to accept fiber optic communication commands. Ensure that the relay address, communication baud rate and parity settings are the same in the relay on the protocol converter.

CURRENT INPUTS TEST

This test verifies that the accuracy of current measurement is within the acceptable tolerances. Apply current equal to the line current transformer secondary (1 & 5A) rating to each current transformer input of the corresponding rating in turn, checking its magnitude using a multimeter. Open the corresponding reading in the relay's measurements, and record the value displayed. Repeat the last step with the other phase currents. The measured current values on the relay is set either in primary or secondary Amperes. If it is set to 'Primary', the values displayed on the relay should be equal to the applied current multiplied by the corresponding current transformer ratio set in the CT ratios'. If it is set to 'Secondary', the value displayed should be equal to the applied current.

VOLTAGE INPUTS TEST

This test verifies that the accuracy of voltage measurement is within the acceptable tolerances. Apply current equal to the line VT secondary winding rating to each VT input of the corresponding rating in turn, checking its magnitude using a multimeter. Open the corresponding reading in the relay's measurements, and record the value displayed. Repeat the last step with the other phase voltages.
The measured voltage values on the relay is set either in primary or secondary Volts. If it is set to 'Primary', the values displayed on the relay should be equal to the applied voltage multiplied by the corresponding VT ratio set in the 'VT ratios'. If it is set to 'Secondary', the value displayed should be equal to the applied phase voltage.

SETTING CHECKS

Setting checks ensure that all of the relay settings (both the relay's functions and configuration settings) for the particular installation have been correctly applied.
There are two methods of applying the settings:

- Transferring them from a pre-prepared setting file to the relay using a portable PC running the appropriate software via the relay's front RS232 port or any communication way, this method is the preferred for transferring function settings as it is much faster and there is less margin for error. If configuration file other than the default settings with which the relay is supplied are to be used then this is the only way of changing the settings.

- Enter them manually via the relay's operator interface. This method is not suitable for changing the configuration setting.

There are two methods of checking the settings:

- Extract the settings from the relay using portable PC running the appropriate software via the front RS232 port or any communication way. Compare the settings transferred from the relay with the original written specific setting record.

- Step through the settings using the relay's operator interface and compare them with the original application-specific setting record.

OVERCURRENT FUNCTION TEST

STEP 1

This test is common for all digital protective relays, because they all have current elements. Connect a simple test circuit as shown in Fig. 3.3-10. On the setting file, select the required setting group (if multiple setting groups are available).

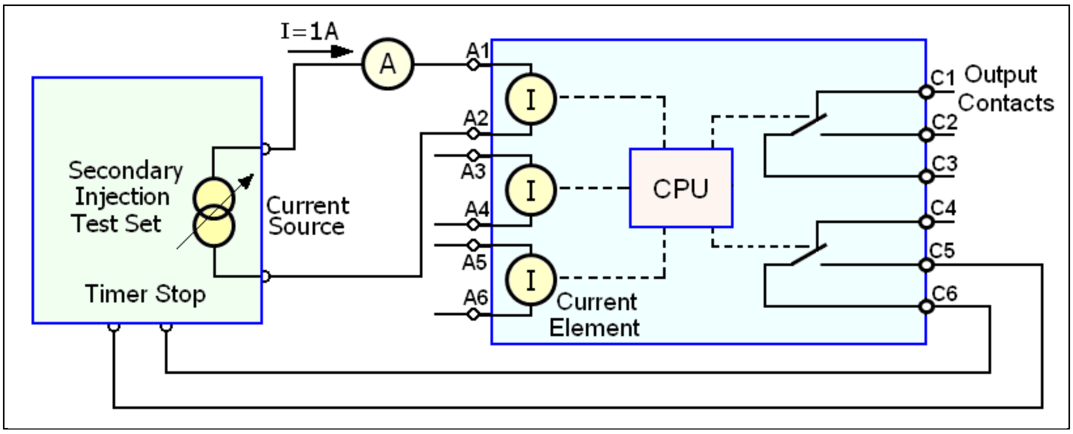


Fig. 3.3-10 Schematic Circuit to Test Overcurrent Elements

STEP 2

On the setting file, define the current for each phase, and adjust the current turn's ratio.

STEP 3

Adjust current setting, frequency, and phase angle.

STEP 4

Adjust the overcurrent time delay, by selecting one of the following two options:

- Definite time overcurrent element.
- Inverse time overcurrent characteristics.

STEP 5

At case of selecting definite time, the program asks for current and time settings.

STEP 6

At case of selecting inverse characteristic, the program asks for a certain curve among multi curves found in the relay manual.

STEP 7

On the configuration file, define the output contact, NC or NO, by determining which output relay has been selected to operate when an overcurrent trip occurs by viewing the relay's configuration file.

STEP 8

Select timer and adjust delay time for delay ON and delay Off.

STEP 9

The overcurrent Direction is set to enable or disable, when disable is selected the overcurrent operate without directionality. When enable is selected, another selection must be done 'Directional Fwd' or 'Directional Rev' as the test detailed already confirms the correct functionality between current and other inputs, which confirm at measurement accuracy is within the stated tolerance.

STEP 10

Connect the output relay so that its operation will operate the continuity of the Megger as shown in Fig. 3.3-9, or to trip the test set and stop the timer, if the timer stop of the test set is used.

STEP 11

Connect the current output of the test set to the 'A' phase current transformer input of the relay terminals, where 1A or 5A current transformers are being used.

STEP 12

If direction element is set to 'Directional Fwd', the current should flow out of terminal A_2 (or into A_2 if set to 'Directional Rev') as shown in Fig. 3.3-10.

STEP 13

If overcurrent status is set to 'Enabled' but configured for voltage controlled overcurrent operation, then rated voltage should be applied to terminals B1 & B2 as shown in Fig. 3.3-11.

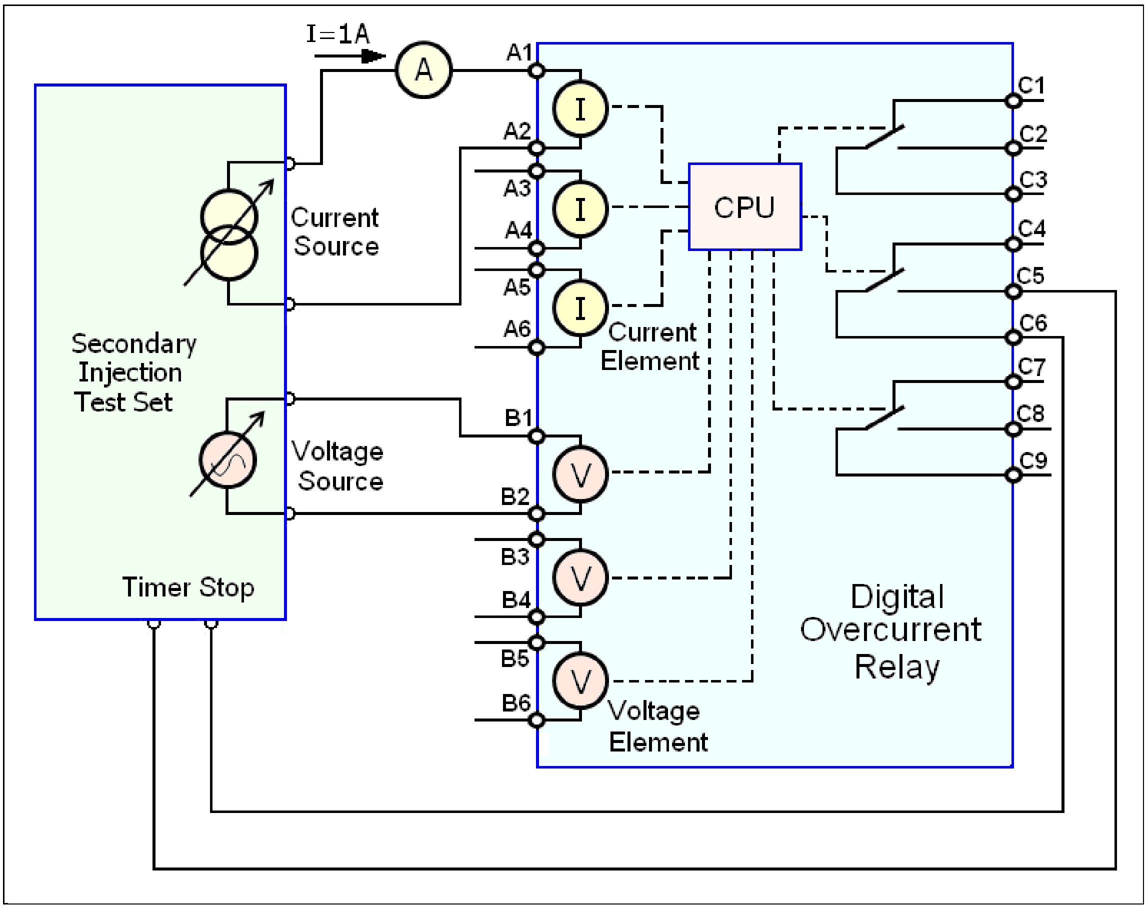


Fig. 3.3-11 Test Overcurrent Elements with Voltage Dependant

STEP 14

Ensure that the timer will start when the current is applied to the relay.

Note: If the timer does not start when the current is applied and stage 1 has been set for directional operation, the connections may be incorrect for the direction of operation set. Try again with the current connections reversed.

STEP 15

During the Test, ensure that the timer is reset.

STEP 16

Apply a current of twice the setting value to the relay and note the time displayed when the timer stops.

STEP 17

Check the operating time, check that the operating time recorded by the timer is within the range of the setting time.

Note: Except for the definite time characteristic, the operating times is defined as a time multiplier number. Therefore, to obtain the operating time at other time multiplier or time dial settings, the time is given in a table, which must be multiplied by a setting from relay manual.

In the case of three-phase tester, it is preferred to test the three phase current elements at the same time, by connecting the other two phases of current and voltage terminals.

RECORD FILE

Sometimes it is called disturbance recorded file, it can store the events, fault cases, and interrupts. Each event can be analyzed from the point of what time it happened, how long time it takes, what type of fault, which breaker has been tripped, and many other information about the event.

MEASUREMENT FILE

All the electrical quantities are monitored live on the relay display unit or through the measurement file. These electrical quantities include 3-phase current, 3-phase voltage, and phase angle, neutral current, delivered active power, Vars, and frequency. The values are set to pull each certain time to retrieve new values.

SETTING OF THE DISTANCE ZONES

Line impedances are proportional to the line lengths and this property is used to calculate the distance from the relay location to the fault. The relay, however, is fed with the current and voltage measured signals from the primary system via instrument transformers CT and VT. Therefore, the secondary value used for the setting is obtained as the following expression,

$$Z_S = \frac{I_{pri}/I_{sec}}{V_{pri}/V_{sec}} Z_{pri}$$

Where I_{pri}/I_{sec} and V_{pri}/V_{sec} are the transformation ratios of the current and voltage transformers, respectively.

In order to cover a section of the line and to provide back-up protection to remote sections, three main protection zones, see Fig. 3.3-12, are set up with the following criteria:

Zone 1: this is set to protect between 80% and 85% of the line length AB and operates without any time delay.

Zone 2: this is set to protect 100% of the line length AB, plus at least 20% of the shortest adjacent line BC and operates with time delay t_2.

Zone 3: this is set to protect 100% of the two lines AB, BC, plus about 25% of the third line CD and operates with time delay t_3.

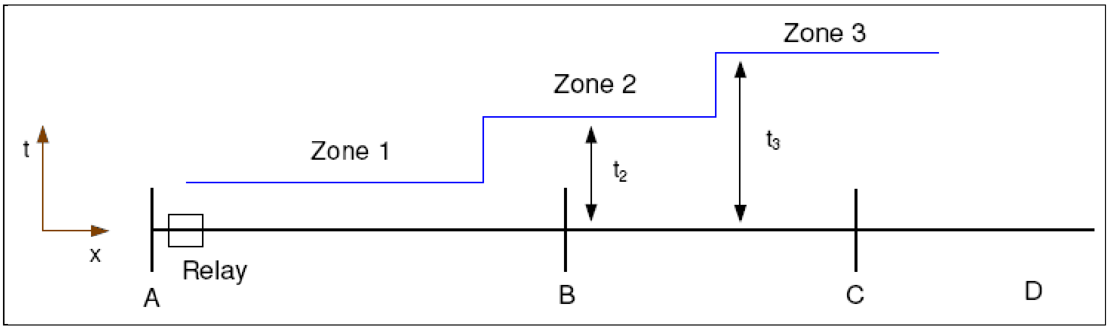


Fig. 3.3-12 Distance-relay protection zones

DISTANCE RELAY TYPES

Distance relays are categorized in two major schemes; switched scheme and full scheme. The block schemes for a switched scheme and full scheme are illustrated in Fig. 3.3-13. In a switched relay, the start elements detect a fault. These elements together with logic blocks determine the correct input signals with respect to the fault type. Zones of operation are decided by timer block. Measuring elements and directional elements decide if the impedance is inside a certain zone and the direction to the fault, respectively. The full scheme relay does not have the start elements. It has measuring elements for each phase, each zone and both phase to phase and phase to ground faults. The operation is faster than that of switched relays.

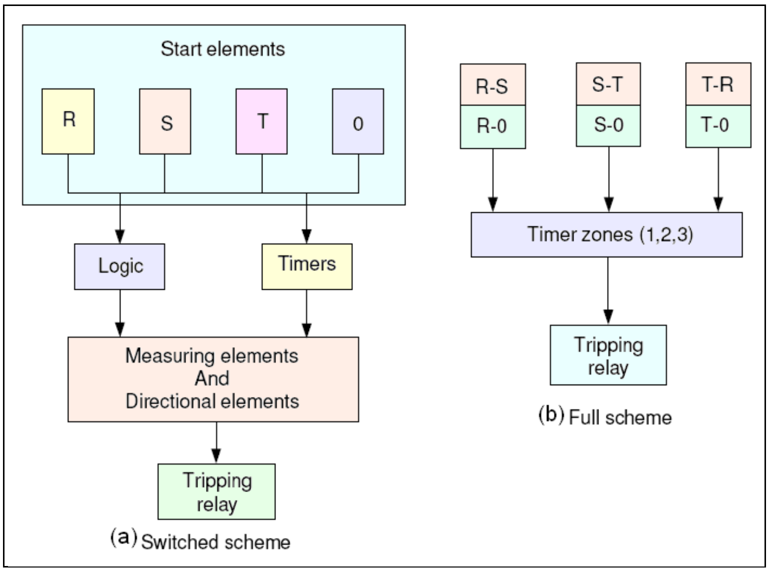


Fig. 3.3-13 Block schemes for a switched and full scheme distance relay

NUMERICAL DISTANCE RELAY

STRUCTURE OF NUMERICAL RELAYS

A numerical relay consists of the following main subsystems:

- Microprocessor
- Analog input system
- Digital output system
- Power supply

Fig. 3.3-14 shows a block scheme of a typical numerical relay.

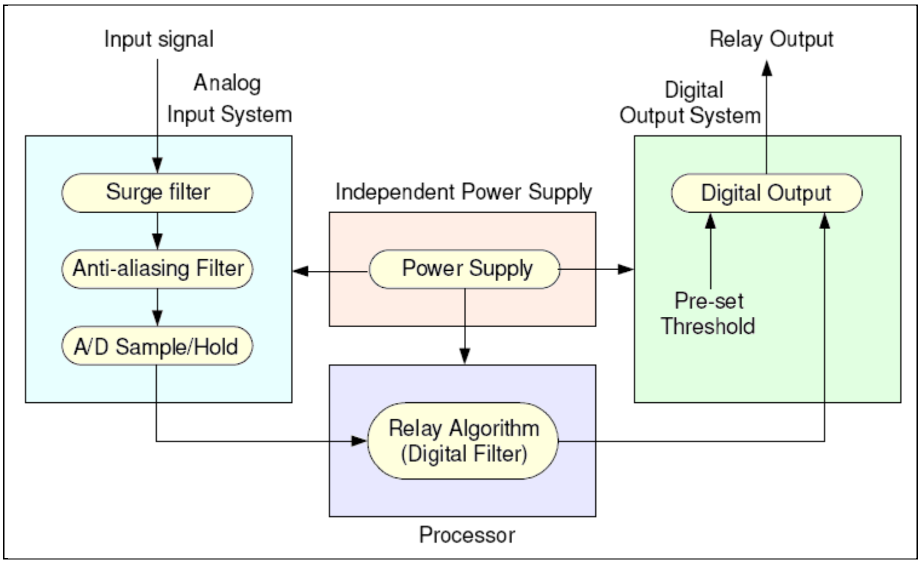


Fig. 3.3-14 Block diagram of a numerical relay

Numerical relays operate on sampled signals and adopt digital computations. Sampling is the process of converting analog input signals, such as current and voltage, into digital input signals. In order to protect the relay from large transients of the input signals a surge filter is used.

An anti-aliasing filter is used to avoid possible errors in reconstructing the input signal carried out after the A/D Sample/Hold section.

The A/D converts the sample values that represent the analog input signals into the digital input signals. However, the conversion is not instantaneous, and for this reason, the A/D system typically includes a sample-and-hold circuit. The sample-and hold circuit provides ideal sampling and holds the sample values by the A/D converter.

The microprocessor containing the relay algorithm is the controller of the numerical relay. The microprocessor most often performs all control, computation, self-test, and communication functions. The algorithm functions as a digital filter to extract the fundamental component of the input signal, based on which the relay operation is carried out.

The signal from the digital filter is compared with the pre-set threshold in the digital output system. The relay operation is decided based on this comparison.

RELAY ALGORITHM

The algorithm is designed to calculate all the necessary calculations to determine the fault cases and to obtain the operating time of the relay elements.

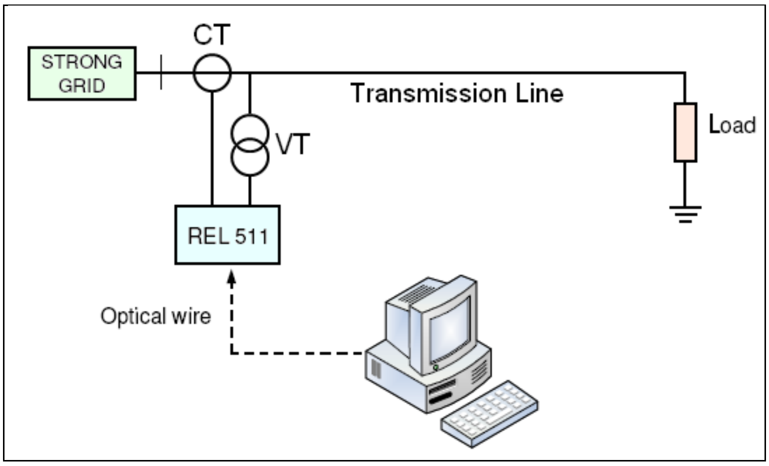


Fig. 3.3-15 Connecting Distance Relay on TL

The relay is based on a full scheme distance protection function. REL 511detects both phase-to-phase and phase-to-earth faults and it has quadrilateral operating characteristics. A separate general fault criterion with advanced characteristics is used for phase selection and as an overall measuring function, which increases the total operating security and facilitates remote backup applications.

The numerical REL 511 line distance protection terminals are designed for the main and backup protection, monitoring, and control of power lines, cables and other primary objects. They can be used in systems with simple or complex network configurations regardless of the type of system grounding.

REVIEW EXERCISE

1. What are the types of digital relay mounting?

2. What does the setting file include?

3. What does the configuration file include?

4. What are the famous communication cable plugs?

5. What is the function of relay record file?

6. What is the function of relay measurement file?

7. What is the function of programmable LEDs?

8. What is the function of un-programmable (fixed) LEDs?

9. What is the function of opto-isolators in the digital relays?

10. What is the function of timer stop in the test set?

TASK 3.3-1
TESTING DIGITAL OVERCURRENT RELAY

OBJECTIVE

Upon completion of this task, the trainee will be able to test digital overcurrent relay, using relay type 7SJ6021 SIEMENS made.

TOOLS, MATERIALS & REQUIREMENTS

- Relay type 7SJ602 SIEMENS made
- Secondary injection test set
- AC ammeter.
- DC power supply (0 - 240VDC).

SAFETY PRECAUTIONS

The participants must wear safety clothes and follow all safety instructions as recommended in the relay workshop.

RELAY DESCRIPTION

The 7SJ602 relay is a numerical overcurrent relay, which in addition to its primary use in radial distribution networks and motor protection. It can also be employed as backup for line, transformer, and generator differential protection. The relay provides definite-time and inverse-time overcurrent protection along with overload and unbalanced-load protection for a very comprehensive relay package. For applications with earth current detection two versions are available:

One version with four current transformer inputs for non-directional earth fault detection. The second version with three current inputs (2 phase, 1 earth/ground) and one voltage input for directional earth fault detection.

The relay function diagram is described as shown in Fig. 1-1.

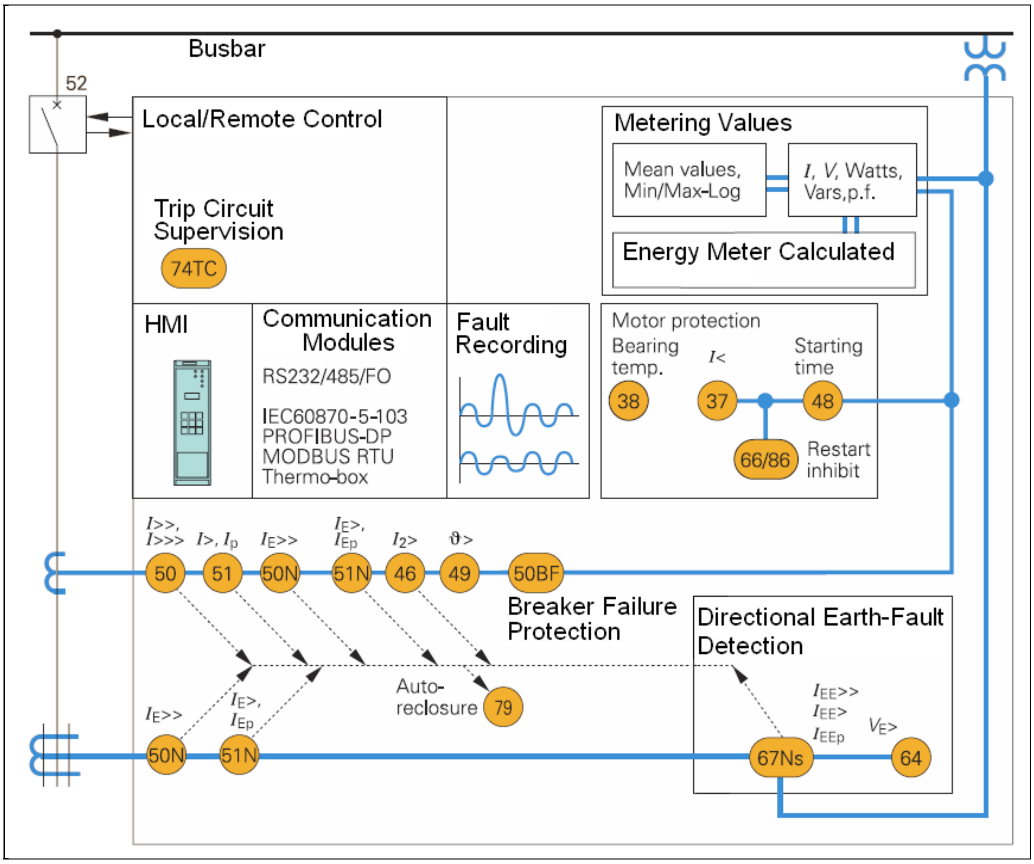


Fig. 1-1 Digital Relay 7SJ602 Function Diagram

ANSI No.	IEC	Protection functions
50, 50N	$I>$, $I>>$, $I>>>$ $I_E>$, $I_E>>$	Definite-time overcurrent protection (phase/neutral)
51, 51N	I_p, I_{Ep}	Inverse-time overcurrent protection (phase/neutral)
67Ns/50Ns	$I_{EE}>$, $I_{EE}>>$, I_{EEp}	Directional/non-directional sensitive earth-fault detection
64	$V_E>$	Displacement voltage
50BF		Breaker failure protection
79		Auto-reclosure
46	$I_2>$	Phase-balance current protection (negative-sequence protection)
49	$\vartheta>$	Thermal overload protection
48		Starting time supervision
66/86		Restart inhibit
37	$I<$	Undercurrent monitoring
38		Temperature monitoring via external device, e.g. bearing temperature monitoring
74TC		Trip circuit supervision breaker control

(a) Front (b) Rear

Fig. 1-2 Digital Overcurrent Relay Type 7SJ602

The specifications and technical information can be found in the relay manual

PROCEDURE

1. Receive the overcurrent relay from your instructor.
2. Apply visual inspection test as discussed in the lesson.
3. From the relay configuration terminals in the manual, identify isolated input terminals, how many, record the terminal label numbers.
4. Identify the output contact terminals, how many, record the terminal label numbers.

5. Identify the AC current inputs, how many, record the terminal label numbers.
6. Identify the earth fault current terminals.
7. Consider the front LEDs functions.
8. Identify the RS232 communication terminal.
9. Identify the power supply and ground terminals.
10. Consider the relay configuration terminals as shown in Fig. 1-3.
11. Install the relay program on the PC and testing the relay elements can be verified as discussed in the lesson.
12. Select the required operating characteristics from the manual (as the application needs) and define it in the setting file.

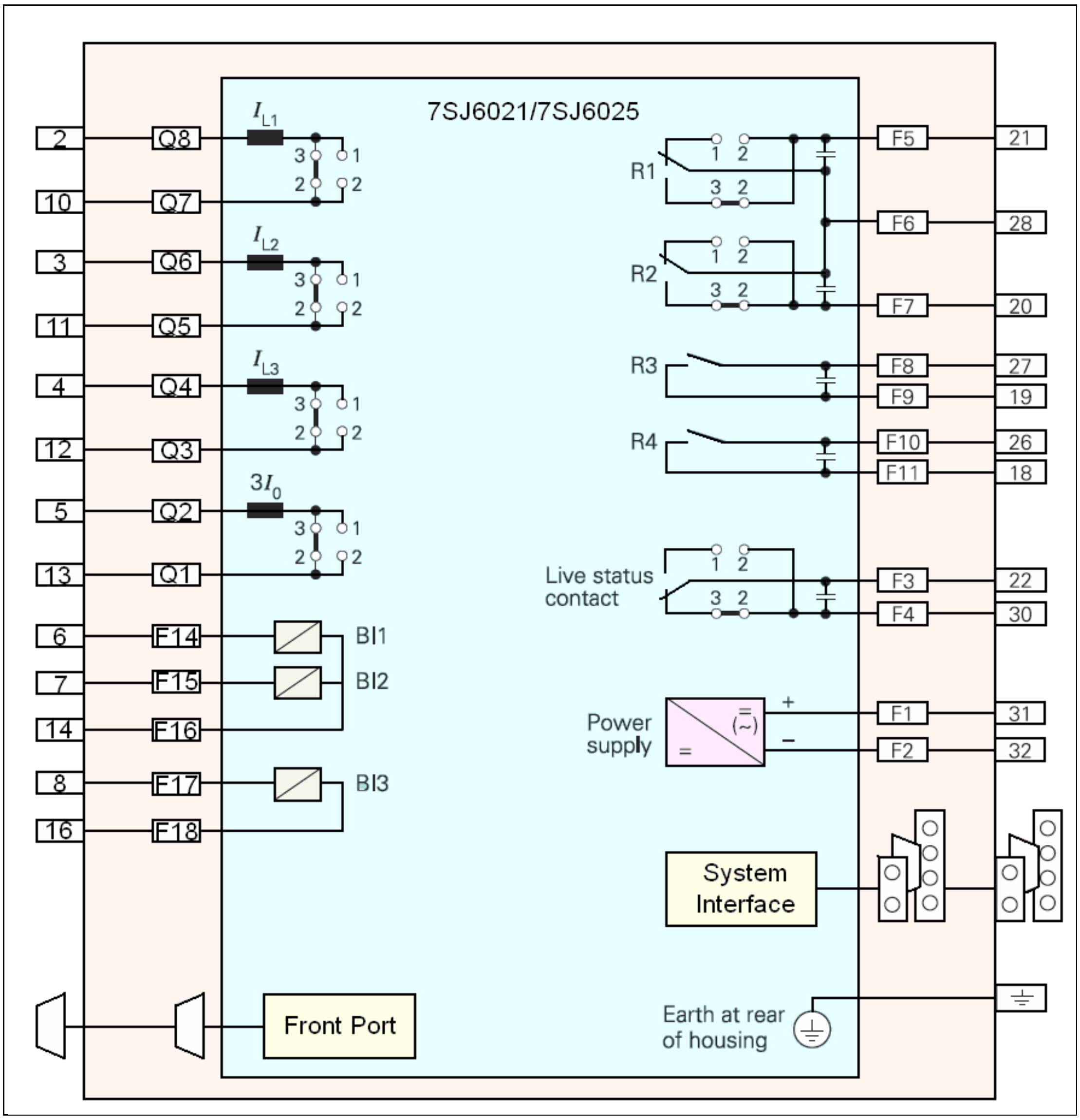


Fig. 1-3 Relay Configuration terminals

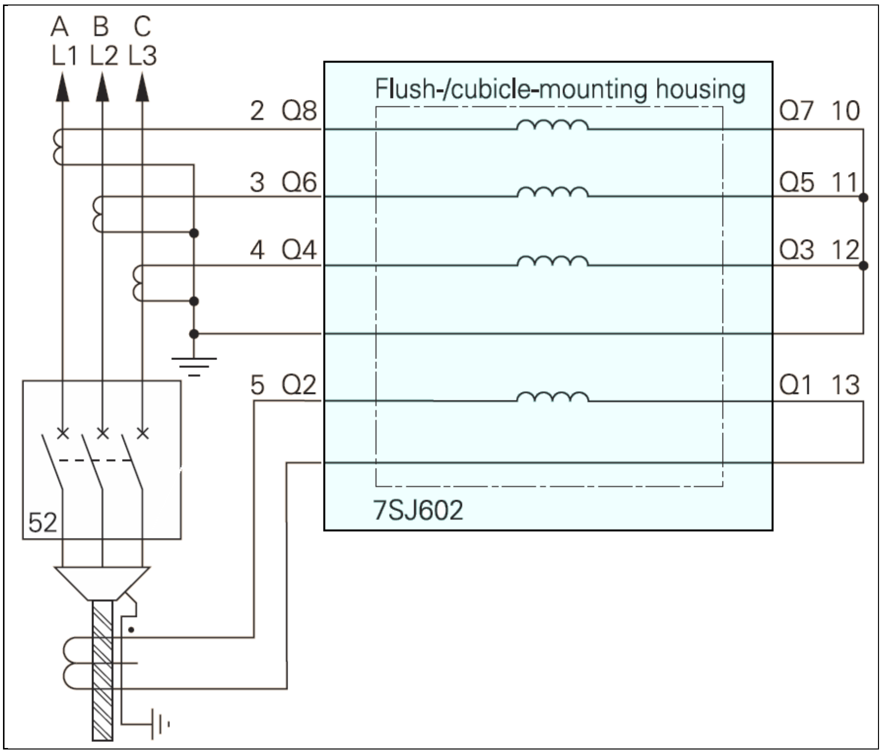


Fig. 1-4 Relay Connection Circuit

TESTING OVERCURRENT ELEMENTS

13. The relay test can be performed as single phase to test each current element individually; hence the unused elements should be disabled on the setting file.
14. Connect the circuit shown in Fig. 1-5.

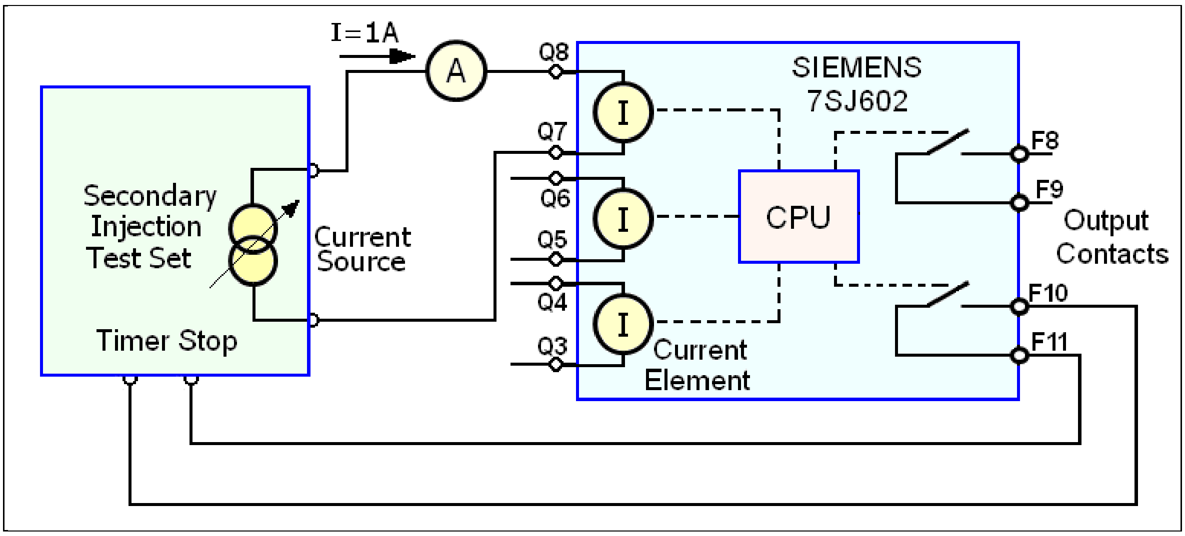


Fig. 1-5 Testing Current Elements of Digital O/C Relay 7SJ602

15. Connect the O/C relay to the PC using RS232 cable, be shore that the relay software was installed previously on the PC.
16. Open the setting file of the relay and fill the required setting values as discussed in the lesson, the relay setting range, pick-up time, and the reset time for the relay can be obtained from the manual.
17. After saving the relay setting file, apply the DC voltage of the power supply to the relay and wait (few seconds) until the relay is ready to operate.
18. Download the setting file to the relay, then configure the required output contacts, timer (if needed), and any other accessories.
19. On the secondary injection test set, adjust the injection current below the rated value, and start injecting the current, you get no trip.
20. Increase the injected current to a value above the rated current, you get tripping LED bright, and the timer count the tripping time.
21. Review the disturbance record file to get the recorded information about the last event, it should agree with the setting values.
22. The earth fault element can be tested as the other current elements has been tested, just rearrange the circuit as shown in Fig. 1-6.
23. Consider the earth-fault element in the setting file, and keep the other configurations of the relay without change.
24. Repeat the last procedure for the earth-fault element and complete the test.

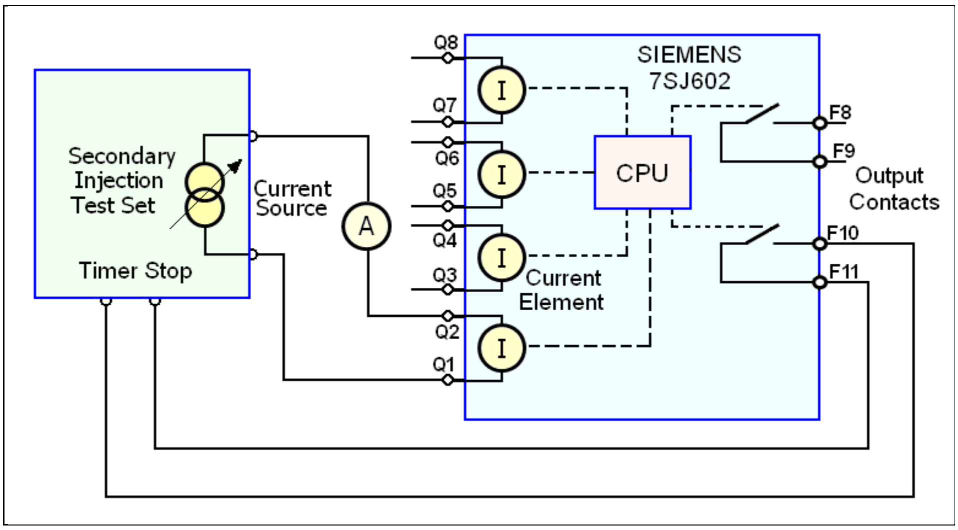


Fig. 1-6 Testing Earth-Fault Elements of Digital O/C Relay 7SJ602

TASK 3.3-2

TESTING DIGITAL DISTANCE RELAY

OBJECTIVE

Upon completion of this task, the trainee will be able to test digital distance relay, using relay type ABB REL-511.

TOOLS, MATERIALS & REQUIREMENTS

- Relay type ABB REL-511
- AC Voltmeter
- DC power supply (0 - 240VDC)
- Secondary injection test set
- AC ammeter
- Relay Manual

SAFETY PRECAUTIONS

The participants must wear safety clothes and follow all safety instructions as recommended in the relay workshop.

Fig. 2-1 Distance Relay type ABB REL-511

INSTALLATION AND SET UP FOR REL 511

RELAY INSTALLATION

DC supply

The relay uses 48V-250VDC supply. Therefore, a converter having input of 200VAC 240VAC and output of 0VDC-120VDC is used to energize the relay. The connection is shown in Fig. 2-2. As shown in the figure, the converter output is connected to the relay through the terminals 11 and 13.

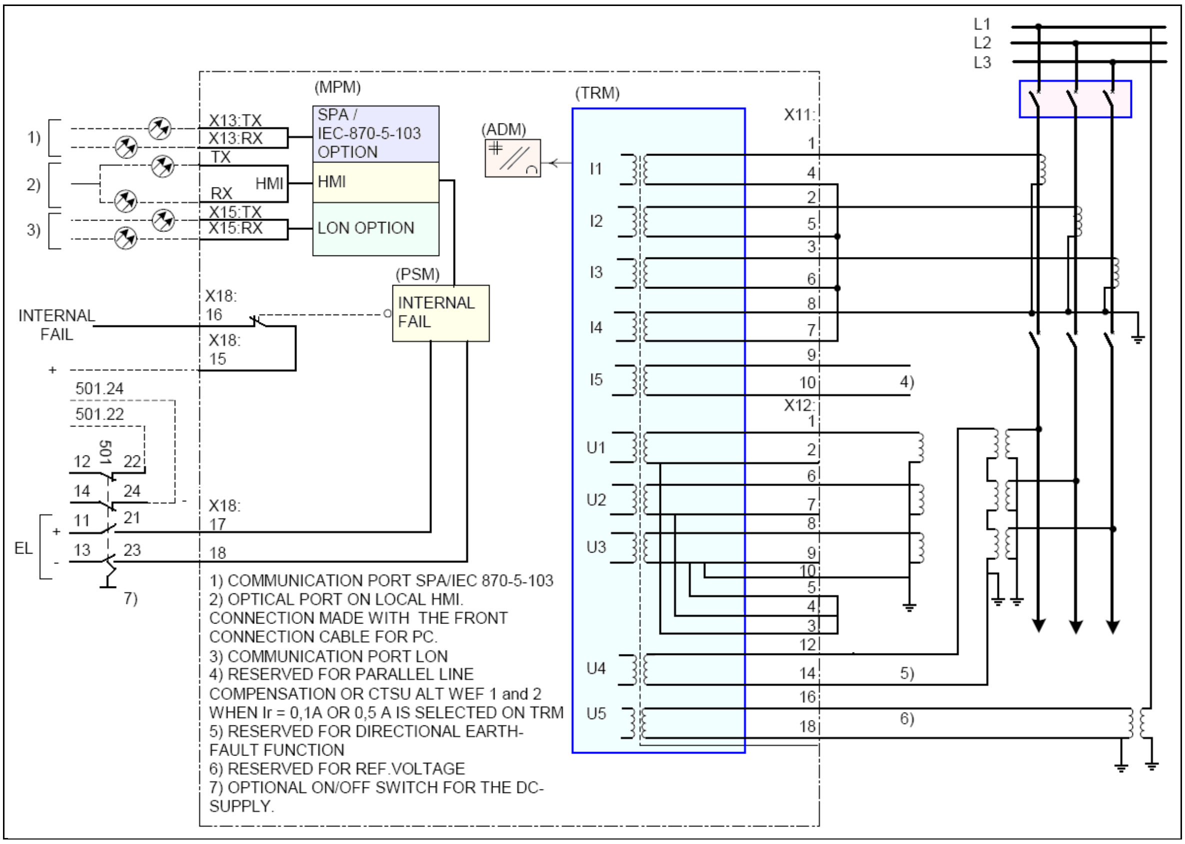


Fig. 2-2 Terminal Diagram for DC Supply

PC TO RELAY CONNECTION

The optical wire is used to make the connection between PC and the relay. Fig. 2-4 shows the human-machine interface (HMI) module in which the optical wire is connected to.

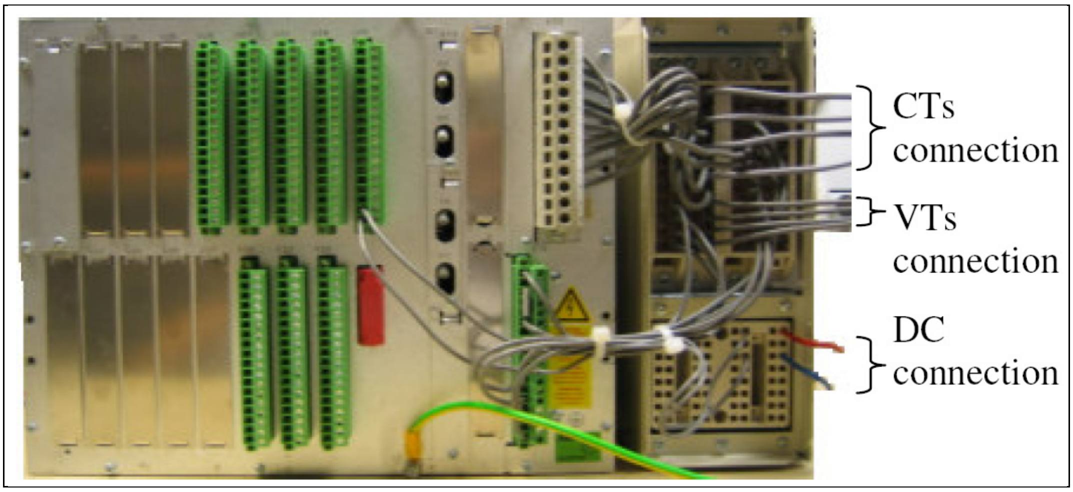


Fig. 2-3 Connection on the rear side of the relay

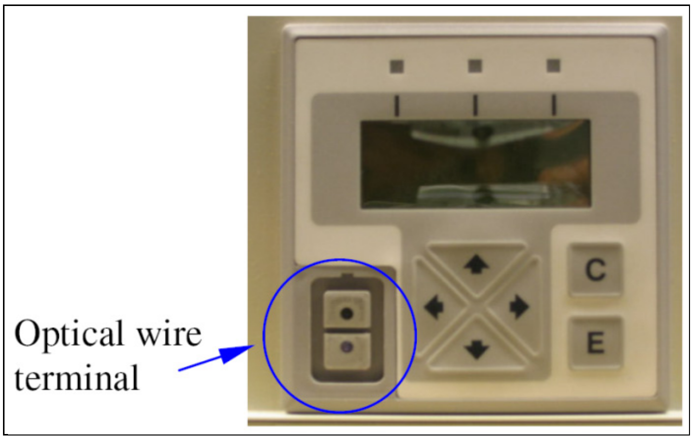


Fig. 2-4 Human-Machine Interface (HMI) Module

CONFIGURATION AND TOOLS USED

The terminal REL 511 is configured using the programming tool CAP 531. This tool enables configuration management, programming and error detection and correction. CAP 531 comprises these views:

- Project tree: Organize terminal and work sheets.
- Work sheet: Create the configuration.
- Page layout: Create drawing forms for printed pages.

A new project tree can be created from within the CAP 531 as shown in Fig. 2-5. It can only have the terminal and work sheets. The graphical configuration is made in the work sheets.

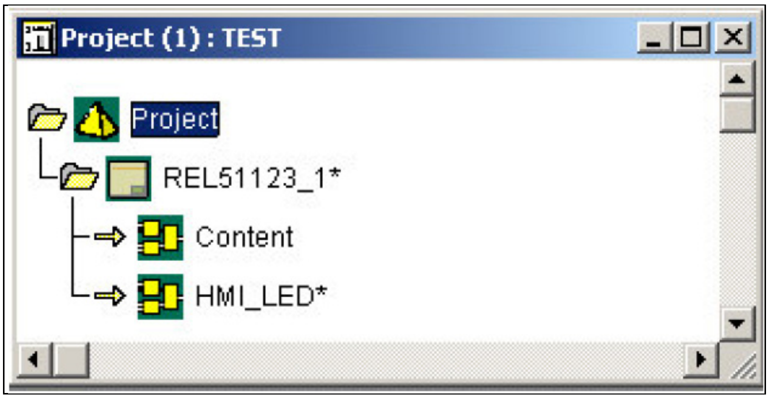


Fig. 2-5 Project Tree

It is important to use the correct set of functions to work with the configuration of a terminal from the beginning. These functions are selected in the Function Selector in the Edit menu. There are many available function blocks for the same function and the Function Selector is used to choose them.

For example, I/O module 01 in the CAP/REL511 program module can be configured to be either as:

- BIM Binary Input Module
- BOM Binary Output Module
- IOM Input Output Module
- IOPSM Input Output Position System Module
- DCM Differential Communication Module

A choice of these modules gives different shape of the function block for the I/O module 01. For instance, the logical I/O module 01 (IO 01) BIM can be compared to BOM as shown in Fig. 2-6.

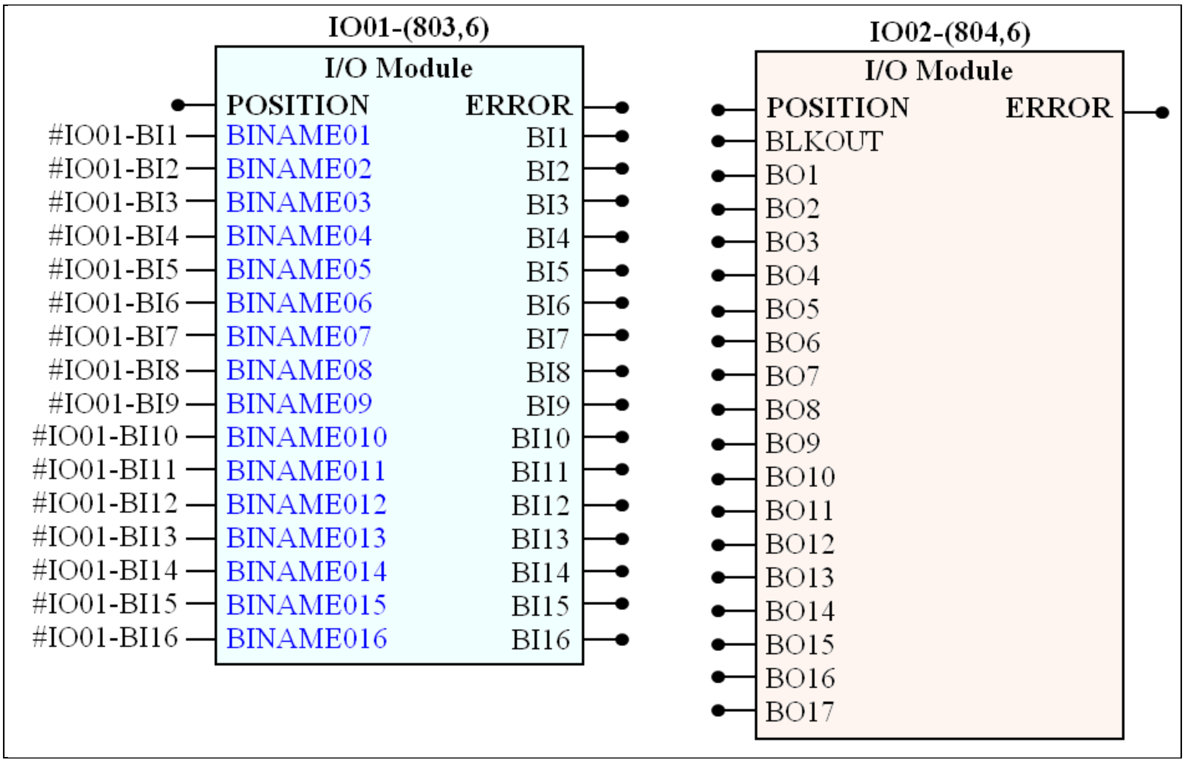


Fig. 2-6 Compare the I/O module as BIM (left) or BOM (right)

The library is updated with a new function block when you select a module in the Function Selector tool and only that selected module can be used in the configuration. The Function Selector can be started as follows:

- Select the terminal in the Project Tree.
- Select the 'Function Selector' in the Edit menu.

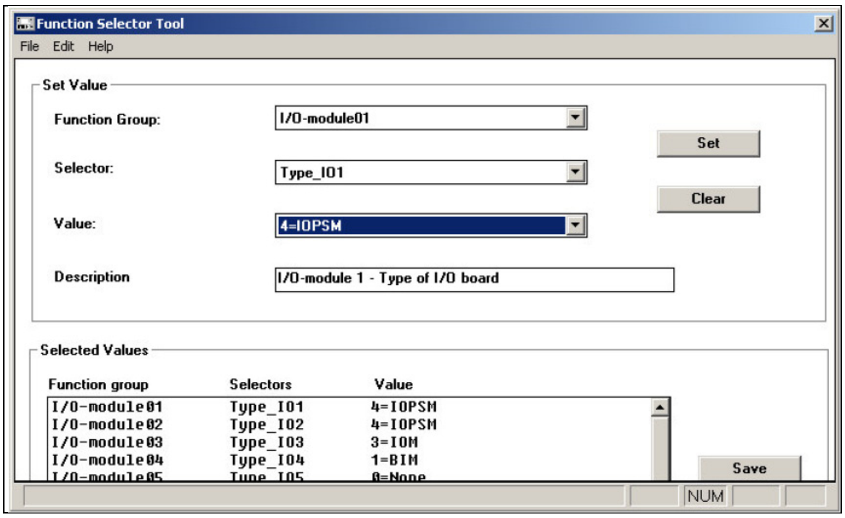


Fig. 2-7 Function Selector

The Function Selector contains the Set Value, which you use to change the function values, and the Selected Values, which give you an overview of all function. The configuration is done in the work sheets as shown in Fig. 2-8. The normal mode used when you work with the configuration in the work sheet and the debug mode is used to test the work sheet configuration.

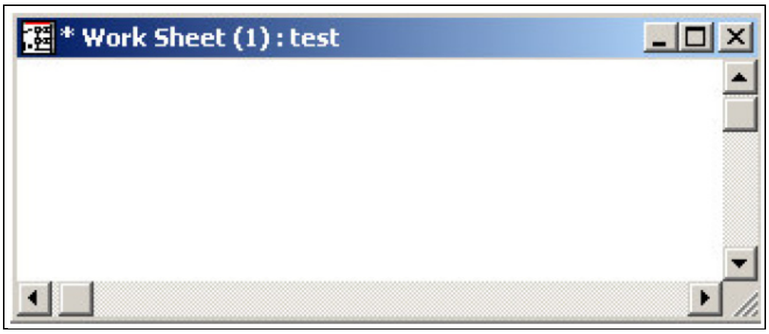


Fig. 2-8 Work Sheet

To open a work sheet:

- Select a work sheet in the Project Tree.
- Double-click the left mouse button or press < Enter >.

Function blocks, variables, setting and text comments are considered as objects in a work sheet. In CAP 531, function blocks represent all the available functions in a terminal. The function block can be one of the following:

- Protection function.
- Control function.
- Monitoring function.
- Logic function.

The function block includes input and output parameters, a type name and function block name as shown in Fig. 2-9.

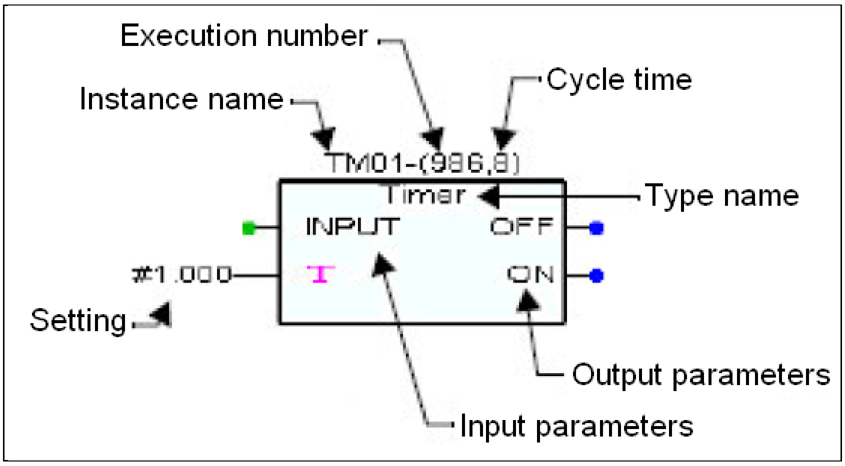


Fig. 2-9 Function block in the CAP 531 Work Sheet

The function blocks can be connected together using the connection mode.

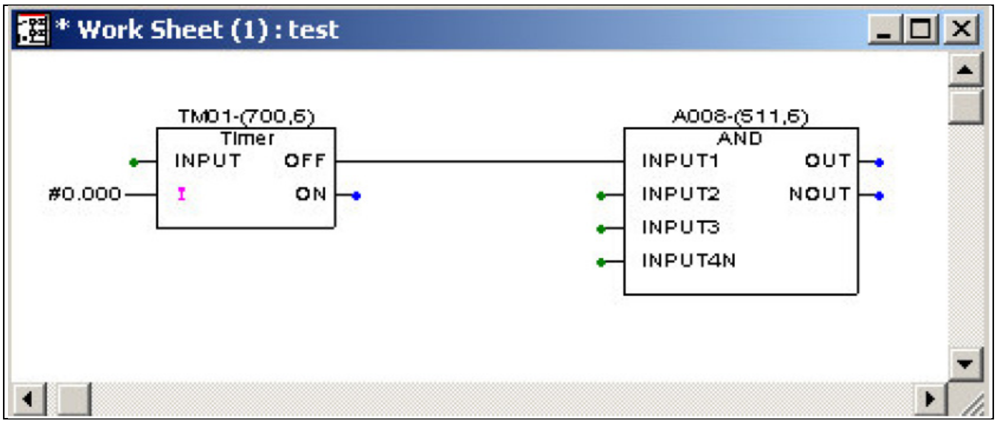


Fig. 2-10 Connecting Two objects

When the configuration preparation is completed, it should be compiled in order to check errors and to prepare the configuration for downloading into the terminal.

INITIAL SET UP OF THE RELAY

Initially, the relay has its default configuration and default parameters. The relay has been configured for three phase trip with the function blocks: distance protection (five zones were set), current functions, scheme communication, voltage and supervision functions, trip logic, auto-reclosing and breaker-failure functions, internal signals, binary inputs and outputs, disturbance report and events for Station Control System.

PARAMETER SETTING

The parameters can be set using the Parameter Setting Tool (PST). PST is a tool for monitoring, service values, protection, and control terminal and relays. From CAP 540,
the PST can be started from the project tree or from a function block within the configuration worksheet as follows:

From the project tree in CAP 540:

- In the project tree, select the wanted terminal instance.
- With a right click select Parameter Setting.

From a function block within a worksheet in CAP 531:

- Open a worksheet for the wanted terminal instance.
- With the right or left mouse button, double-click the wanted function block. The Function Block dialog appears, then click Parameter Settings.

When the parameter tool starts, the main window according to Fig. 2-11 appears.

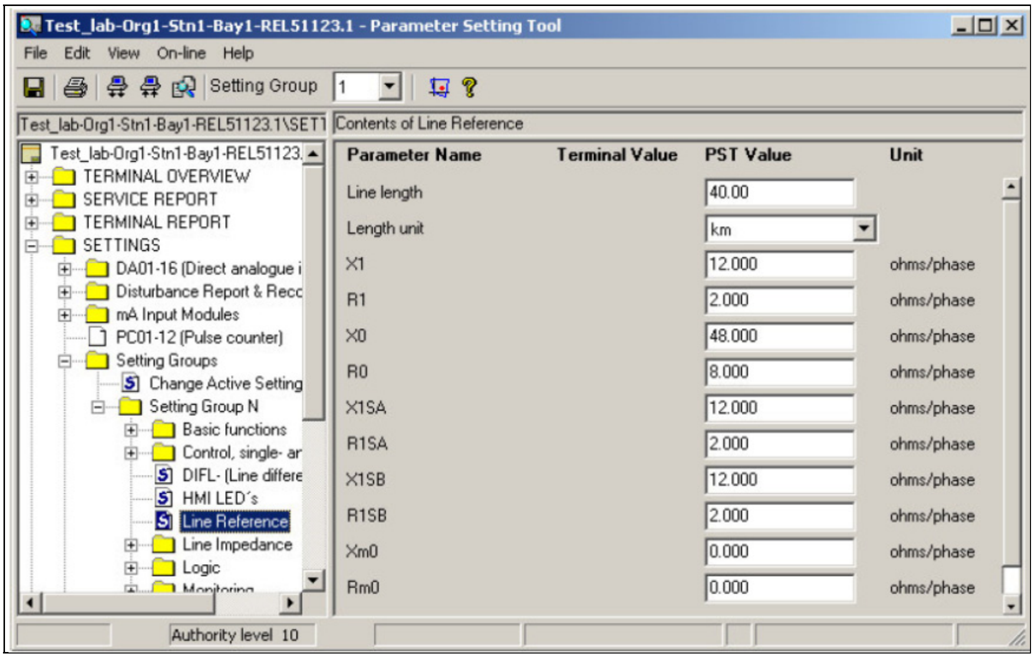


Fig. 2-11 Main Window of Parameter Tool

The terminal tree being on the left side of the window shows the structure in which the parameters for a terminal instance are organized. When a parameter is selected in the

terminal tree, a list of parameters is shown. For each parameter the window will display its name, its value in the terminal, its value in PST and its unit. The parameter value can be edited directly in the PST Value field. A changed value is shown in bold and in the color blue.

SETTING FOR ANALOGUE INPUTS MODULES

The analogue signals fed into the relay should be set in order to get the real values of the primary side of the line model. These setting values are the secondary base values and nominal primary to secondary scale values of the current transformers and voltage transformers. In this test, the base values of current and voltage are 1A and 69V, respectively. The nominal scale values for current transformers and voltage transformers are 100 and 3.347, respectively.

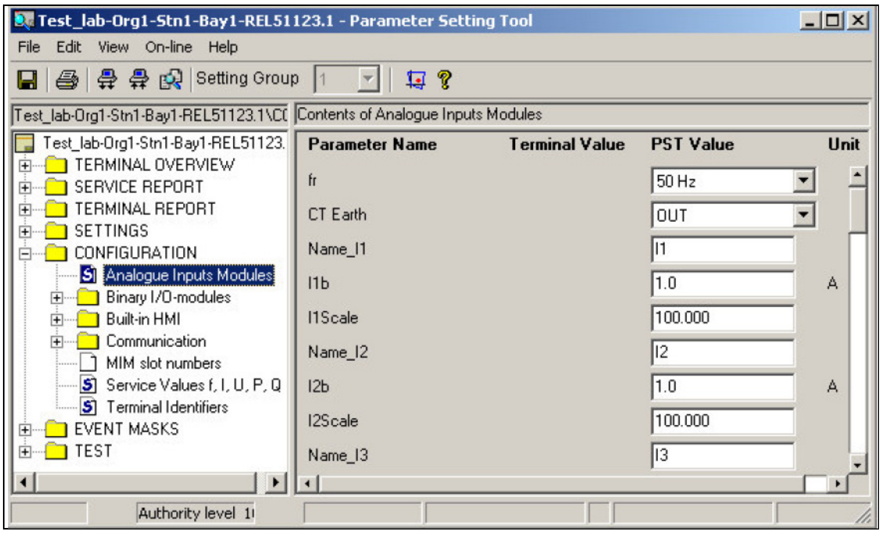


Fig. 2-12 Analogue Inputs Modules parameters

SETTING FOR DISTANCE ZONES

The fundamental rules have been discussed in the earlier chapter. The following values, see Fig. 2-13, have been used for the settings,

- Zone 1: covers 85%AB, forward direction.
- Zone 2: covers 100%AB + 30%BC, forward direction.

- Zone 3: covers 100%AB + 100%BC + 25%CD, reverse direction.

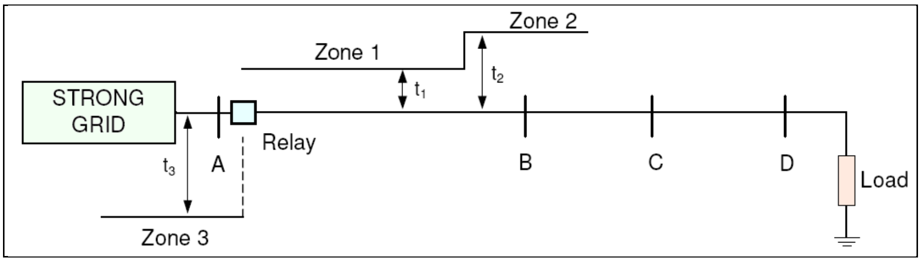


Fig. 2-13 Grading Chart of Setting Zones for Testing

The data of the line model AB, BC, CD for positive sequence is given in Table 2.1.

Line	Reactance X1 [:/phase]	Resistance R1 [:/phase]
AB	2.84	0.23
BC	0.95	0.08
CD	0.95	0.08

Table 2.1 Data for lines AB, BC, and CD

PERFORMED EXAMPLE

POWER SYSTEM MODEL DESCRIPTION

Assume power system having transmission line of a 400kV, and the following parameters:

$X_1 = 50.4\Omega$/phase,

$R_1 = 4.17\Omega$/phase.

Zero sequence impedance $Z_0 = 3Z_1$

RELAY PARAMETERS:

Current: Rated Ir = 1A

Nominal range: (0.2 -30) * Ir

Operative range: (0.004 - 100)*Ir

Permissive overload: 4*Ir continuous, 100*Ir for 1 s

Voltage: Rated Ur = 110V,

Nominal range: (80 -120)% of Ur

Operative range: (0.001 – 1.5)* Ur

Permissive overload: 1.5* Ur continuous, 2.5* Ur for 1 s

DC supply for relay: 48 – 250 V.

DISTANCE ZONES

Zone 1: 85% AB, time delayed = 0, forward direction.

Zone 2: AB + 30% BC, time delayed = 0.25 s, forward direction.

Zone 3: AB + BC + 25% CD, time delayed = 0.35 s, reverse direction.

Load P = 9 kW

AB = 3 π-sections

BC = CD = 1 π-section

F1, F2: Faults locations in Zone 1 and Zone 2, respectively.

Fault resistor $R_f = 5\Omega$. And Timer is set to be 0.5 s.

Setting for zone parameters can be done on the local human-machine interface (HMI) unit under the menu:

Setting / Functions / Group 1 / Impedance / ZM *n* n = 1,2,3.

H: Calculate the setting values for the impedance fault detection of the three zones, according to Figure 2 and the given data.

Note: All of the setting values are calculated for the secondary side based on the following expression:

$$Z_S = \frac{I_{pri}/I_{sec}}{V_{pri}/V_{sec}} Z_{pri}$$

Where I_{pri}/I_{sec} and V_{pri}/V_{sec} are the transformation ratios of the current and voltage transformers with nominal values of 100/1 and 230/69, respectively.

SETTING FOR GENERAL FAULT CRITERIA (GFC)

The general fault criteria serve as an overall fault detection and phase selection element in all kinds of networks. The signals produced by the GFC measuring elements serve for different parts of the distance protection. These are indication of the faulty phases, phase selection for the zone measuring elements, general criteria for the operation of the trip logic and time delayed trip as a backup function to the zone measuring elements.

As can be seen in Fig. 2-14, the zone measuring element characteristics is within that of the GFC, thus to get a trip signal the GFC must be fulfilled.

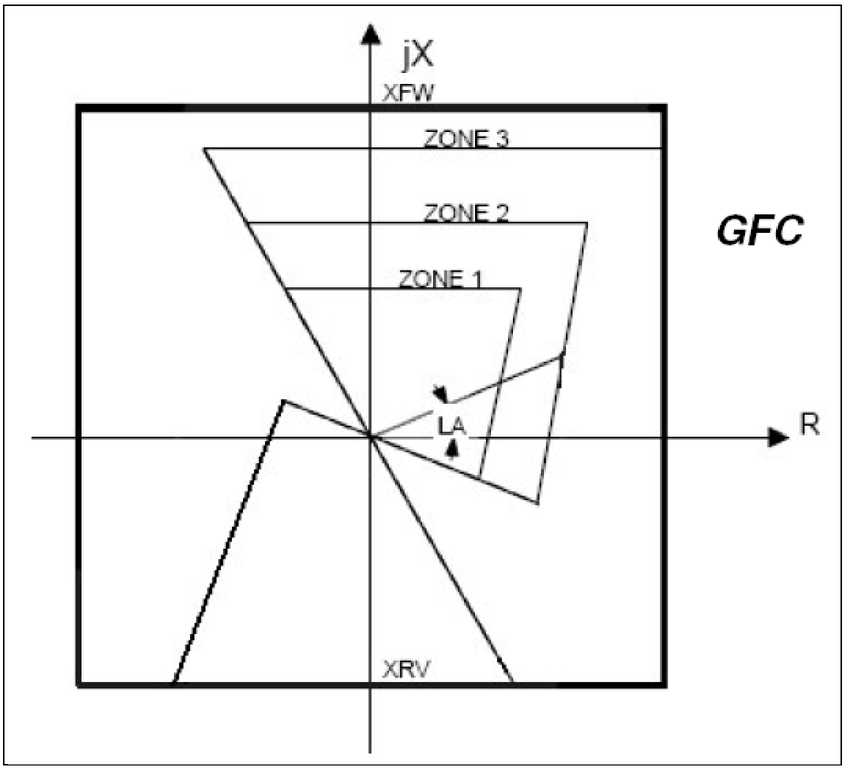


Fig. 2-14 Operating characteristics of the GFC and zone measuring elements

H: Calculate and set the parameters of the GFC. (For definition of the parameters)

RLd… …

X1RvPP… …

X1FwPP… …

RFPP… …

X1RvPE… …

X1FwPE… …

X0RvPE… …

X0FwPE… …

RFPE… …

The default values are used for the following parameters: ARGLd, INReleasePE, INBlockPP, IP>, IN>.

The following values should be used:

tPP = 0 s, tPE = 0 s.

Note: The setting range of GFC should cover all of the zone characteristics.

Setting of the GFC parameters can be done on the local human-machine interface (HMI) unit under the menu:

Setting / Functions / Group 1 / Impedance / Gen Fault Criteria.

Setting of line reference for the Fault Locator (FLOC)

The FLOC provides the distance to the fault together with information about the measuring loop that has been used in the calculation.

H: Calculate the setting values for the FLOC. (For definition of the parameters)

X1… …

X0… …

R1… …

R0… …

The following values should be used:

X1SA = 0.001 Ω, R1SA = 0.001 Ω, X1SB = 1500 Ω, R1SB = 1500 Ω, Xm0 = 0Ω, Rm0 = 0 Ω.

Setting of the FLOC parameters can be done on the local human-machine interface (HMI) unit under the menu:

Setting / Functions / Group 1 / Line Reference.

Exercise in the Laboratory

Carry out the following tests:

1. Single-phase-ground fault
2. Double-phase fault
3. Double-phase-ground fault
4. Phase to phase fault

Faults are applied by optional process exist in the digital tester.

Programs / Disturbance Handling / Terminal list

Note: To upload the disturbance report from the terminal to the PC the procedure below must be followed:

- Plug the cable to the optical contact under the local HMI of the terminal.
- Plug the other end of the cable to the COM port of the PC. The COM port of the PC are two, therefore if you plug the cable to COM port 1 or COM port 2 it must be then set on the PC as COM 1 or COM 2 respectively. This can be done by opening the CAP 540 project Test lab, highlight the Stn1 then set it at:

Settings / Communication settings / Communication parameters

- Set the slave number and the baud rate to 30 and 9600, respectively in the terminal. The slave number and the baud rate settings in the terminal can be done on the local HMI at:

Configuration / Terminal Com / SPA Com / Front

Set the slave number and the baud rate in the PC by opening the CAP 540 project Test lab. Highlight the Stn1 then set it at:

Settings / Communication settings / Communication parameters

The slave number and the baud rate must be the same for both the PC and the relay. Describe and explain the results.

- Switch-on the Dead line detection (DLD), remove one of the three-phase lines that used to connect the relay to the voltage transformers and observe the LED. Then switch-off the DLD.

Operating mode for DLD can be changed on the local HMI under the menu:

Setting / Functions / Group 1 / Deadline Det

- Increase the load to 18 kW and observe the LED.

The setting can be obtained from the relay via manual through HMI, or using software of the relay program.

The events and disturbance records can also be retrieved again by the same software.

ENERGIZING THE RELAY TERMINAL

After checking the connection to the external circuitry, when the terminal is energized the window on the local HMI remains dark. After a few seconds the green LED starts

flashing and then the window lights up. Then after some seconds the window displays 'Terminal Startup' and the main menu is displayed. The upper row should indicate 'Ready' . A steady green light indicates a successful start-up.

If the upper row in the window indicates 'Fail' instead of 'Ready' and the green LED is flashing, an internal failure in the terminal has been detected. Refer to the Self-supervision function in the Installation and Commissioning manual pages 40 - 42 to investigate the fault. For a successful start-up the appearance of the local HMI should be as shown in Fig. 2-15.

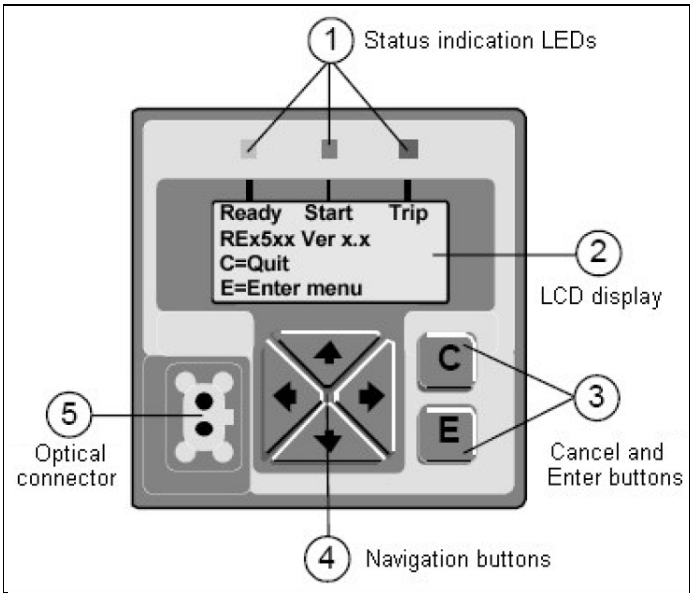


Fig. 2-15 Operating on HMI

LOG ON AND BUILD A NEW PROJECT TREE

When starting CAP 540 the following dialog appears:

You should fill in User Name and Password and click OK as follows:

User Name: system administrator

Password: a10

When you have logged on, you can create a new project tree by selecting **File/New Project.** After **t**yping the file name in the New Project dialog box and clicking OK, a project structure down to Bay level will be created with default names.

Right click on the nodes and select Add to add more nodes to your project. The last level is the Terminal level. Right click on a Bay and select Add. In the Terminal Modules dialog select REL 511 V2.3 Line Protection. Type in a vacant slave number (it must be unique for each terminal that belongs to the same SPA loop) and click OK. In our case, we use the number 30.

SETTING AND CONFIGURING THE TERMINAL

The specific values for each setting parameter and the configuration file have to be available before the terminal can be set and configured.

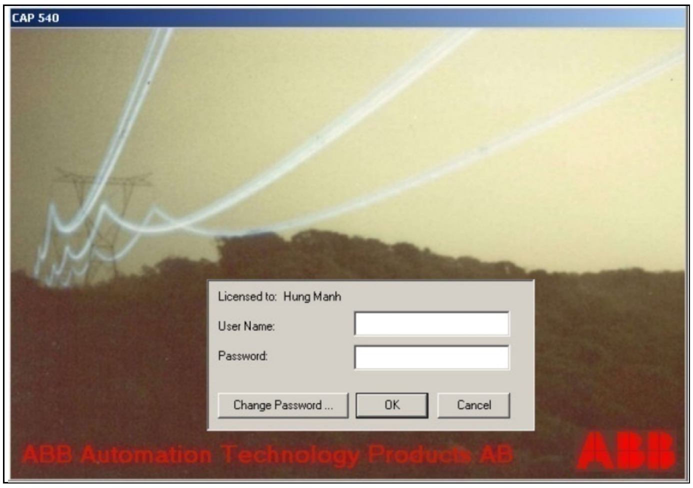


Fig. 2-16 Inserting Password

You should fill in User Name and Password and click OK as follows:
User Name: system administrator
Password: a10
When you have logged on, you can create a new project tree by selecting **File/New Project.** After typing the file name in the New Project dialog box and clicking OK, a project structure down to Bay level will be created with default names.
Right click on the nodes and select Add to add more nodes to your project. The last level is the Terminal level. Right click on a Bay and select Add. In the Terminal Modules dialog select REL 511 V2.3 Line Protection.

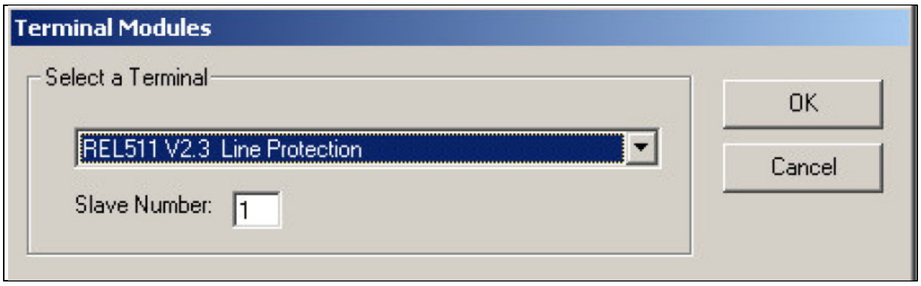


Fig. 2-17 Setting for Terminal Modules

Type in a vacant slave number (it must be unique for each terminal that belongs to the same SPA loop) and click OK. In our case, we use the number 30.

SETTING AND CONFIGURING THE TERMINAL

The specific values for each setting parameter and the configuration file have to be available before the terminal can be set and configured.

Each function included in the terminal has several setting parameters that have to be set in order to make the terminal behave as intended. The setting file can be prepared using the parameter setting (PST), which is available in the CAP 540. All settings can be entered manually through the local HMI or downloaded from a PC. Front port communication has to be established before the settings can be downloaded. The configuration can only be downloaded through the front connector on the local HMI.

COMMUNICATION SETTINGS

Click on Settings menu or right click on a station node and select Communication Settings. The dialog can only be opened if a station node is selected.

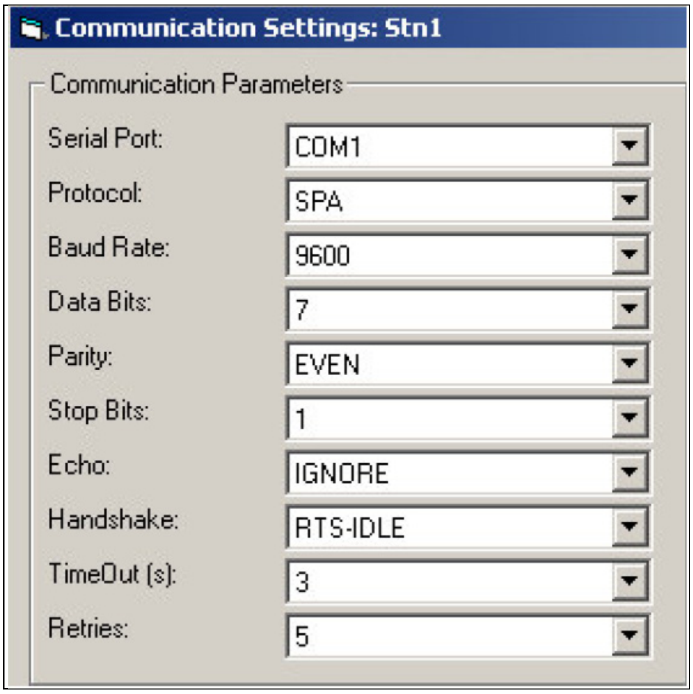


Fig. 2-18 Setting for Communication Port

The Serial Port number depends on the configuration of the PC. The Baud Rate must be 9600 so that it corresponds to the setting of the front port of the terminal. The Slave Number and the Baud Rate settings must be equal in the PC program and the terminal. The Slave Number and the Baud Rate settings in the terminal are done on the local HMI at: Configuration / Terminal Com / SPA Com / Front

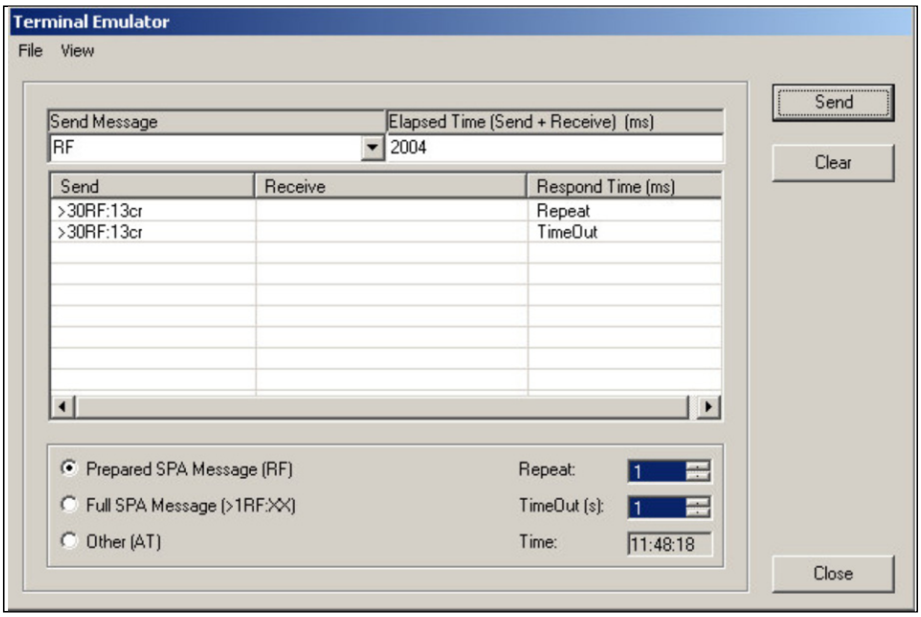


Fig. 2-19 Fault Tracing Simulator

Before start communicating to a terminal, make sure the communication setup in CAP 540 is correct. Terminal Simulator is used for fault tracing. Start the Terminal Simulator by selecting a terminal in the project structure and then select Terminal Simulator in the Tools menu.

If “ Repeat” and Time Out” appear in the Respond Time after clicking Send as shown in Fig. 2-19, the communication set up is incorrect and it should be checked again.

UPLOAD CONFIGURATION

The entire configuration is stored in the terminal and it can be uploading to the PC. For back-up purposes and off-line engineering, a copy of the terminal configuration should be kept on the PC system. Start the Upload Configuration by selecting the terminal in the project tree and then select Upload Configuration in the On-line menu.

DOWNLOAD THE CONFIGURATION

To download the configuration to the terminal:

- Select the terminal that you want to download in the Project Tree.
- Select Download Configuration in the On-line menu, and the Download configuration dialog appears.
- Select Download PST configuration if relevant, click Yes, and downloading starts by uploading the list of available functions.

The Compare Configuration function starts automatically. If the downloading has been successful and there are no differences between the function libraries in the terminal and in the configuration, no differences will be detected in the comparison process. If differences appear in the comparison list, then start the downloading procedure again.

DISTURBANCE HANDLING

The disturbance report stored in the terminal provides the network operator with proper information about disturbance in the primary network. To upload the disturbance report to the PC:

- Select the Terminal level and right click.
- Continue with Disturbance Handling and with Terminal Disturbance List.

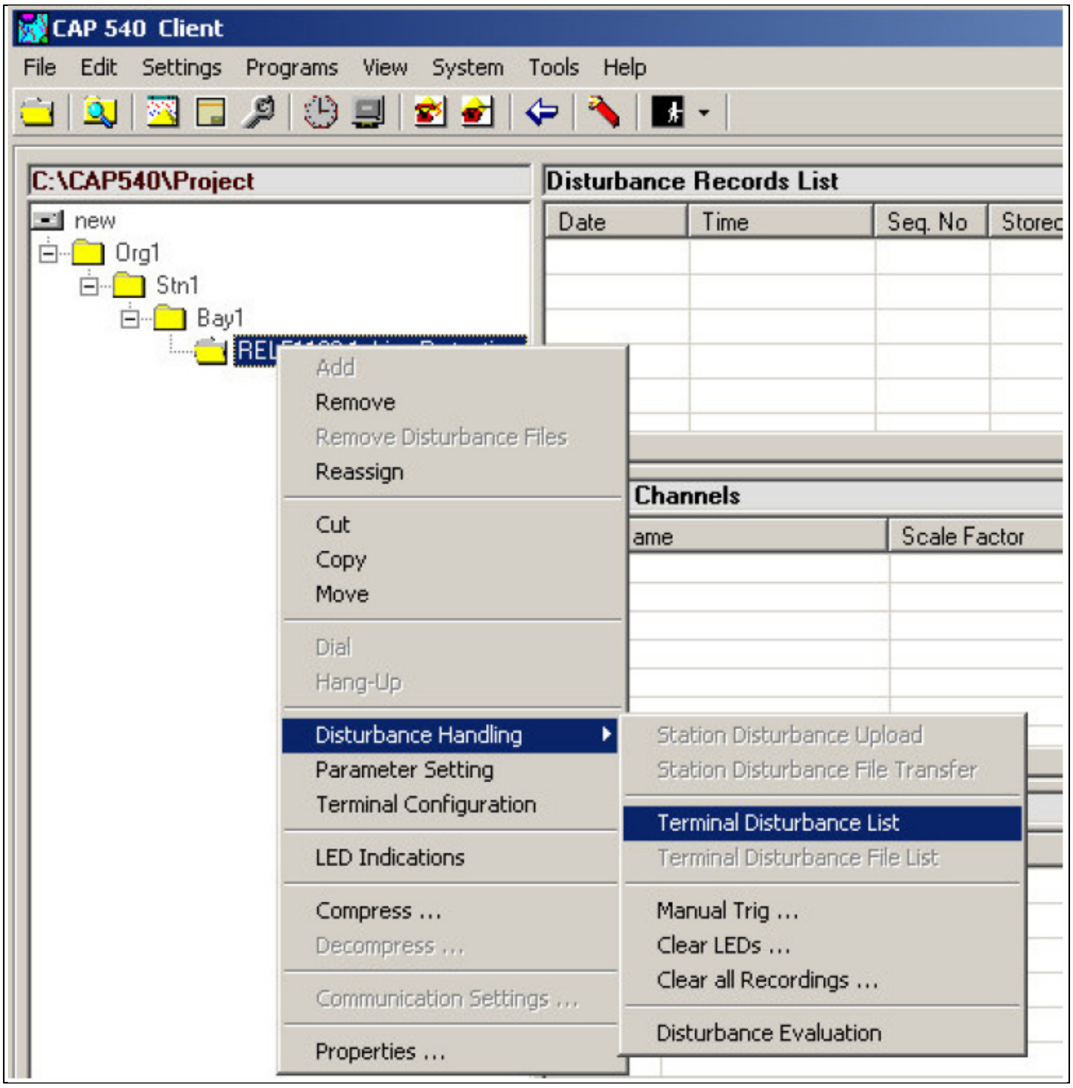


Fig. 2-20 Retrieving Disturbance List

TASK 3.3-3
TESTING DIGITAL DIFFERENTIAL RELAY

OBJECTIVE

Upon completion of this task, the trainee will be able to test digital differential relay, using relay type 7UT61 SIEMENS made.

TOOLS, MATERIALS & REQUIREMENTS

- Relay type 7UT61 SIEMENS made
- Secondary injection test set
- AC ammeter.
- DC power supply (0 - 240VDC).

SAFETY PRECAUTIONS

The participants must wear safety clothes and follow all safety instructions as recommended in the relay workshop.

RELAY DESCRIPTION

The 7UT613 relay has the following input/output terminals:
It has 11 current inputs with jumper position for selecting (1A, or 5A).
It has three voltage inputs.
It has five binary inputs.
It has eight binary outputs.

The relay has the following protection elements:

Differential element	87T/G/M/L
Restricted Earth fault	87 N
Time overcurrent, phases	50/51

Time overcurrent, $3I_0$	50N/51N
Time overcurrent; earth	50G/51G
Time overcurrent, single phase	
Negative sequence	46
Overload IEC 60255-8	49
Overload IEC 60354 (hot spot)	49
Over-excitation V/Hz	24
Breaker failure	50BF
Lockout	86

The relay can protect three end protection objects.

(a) Front (b) Rear

Fig. 3-1 Digital Differential Relay Type 7UT613

The specifications and technical information can be found in the relay manual

The following connection can be used to protect three end protection objects, such as transformer, feeder, motor, and generator.

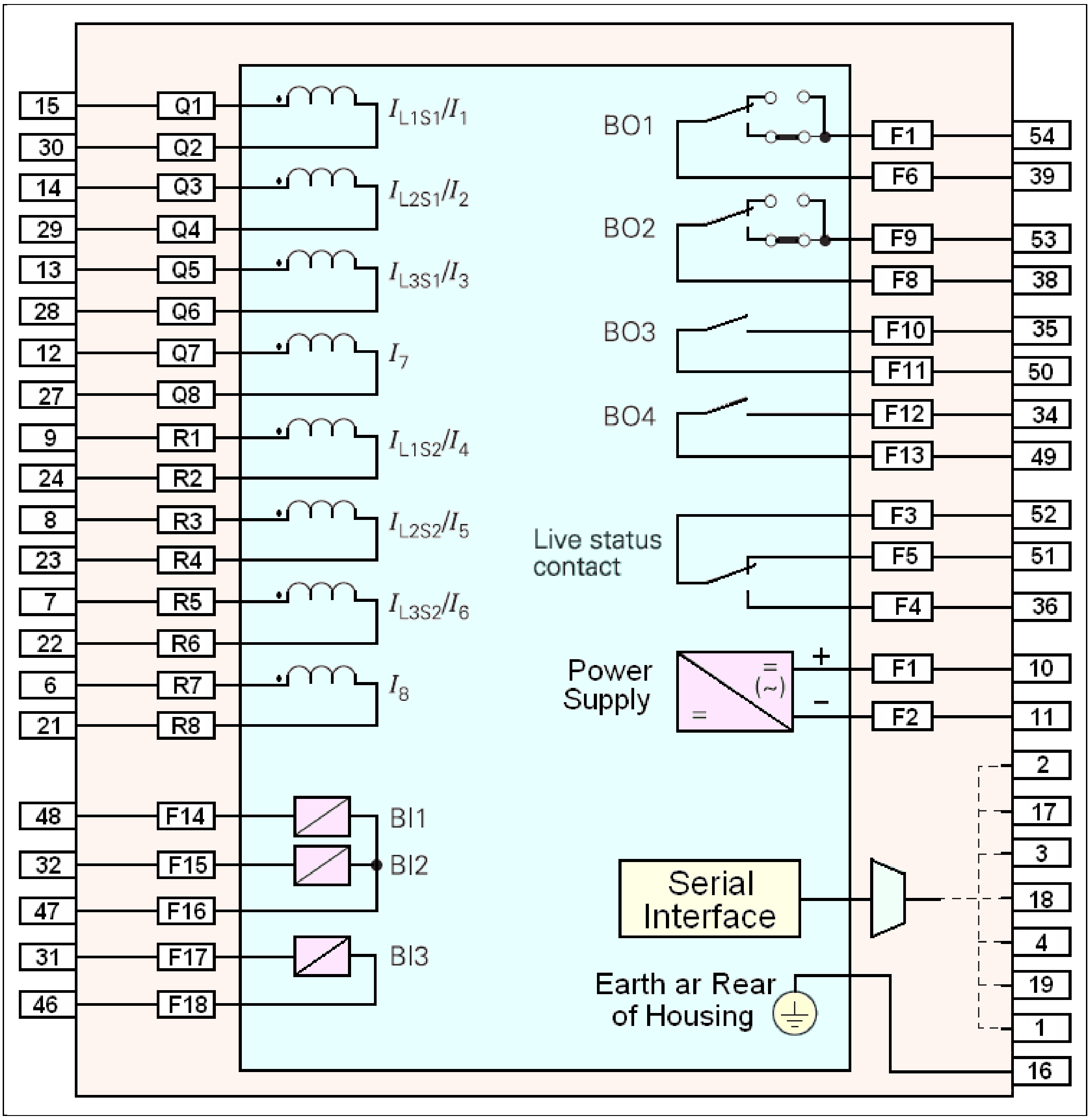


Fig. 3-2 Relay Configuration terminals

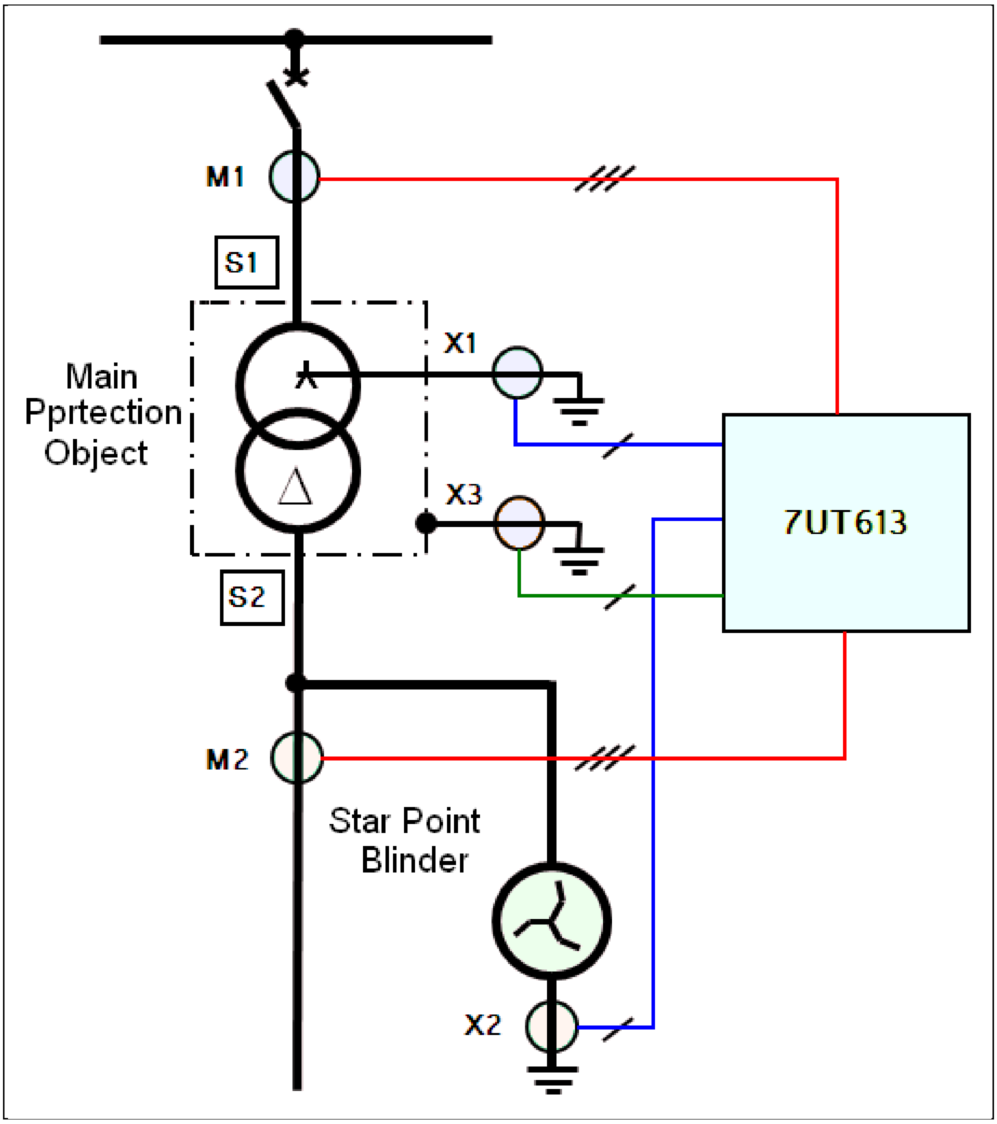


Fig. 3-3 Digital Relay 7UT613 Function Diagram

TESTING OVERCURRENT ELEMENTS

Testing any of the current elements (50 or 51) can be done on the relay individually. Open the setting file either manually or through software and define the selected element, the required contact, and delay time. Save and load the setting file to the relay, connect the test circuit as shown in Fig. 3-4.

Continue the test procedure as illustrated in task 3.3-1.

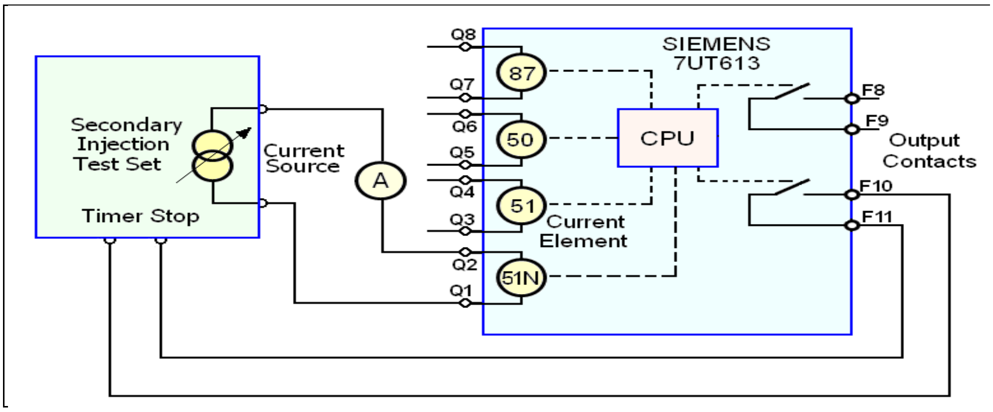


Fig. 3-4 Testing Current Elements of 7UT613 Relay

TESTING DIFFERENTIAL ELEMENT

On the setting file, define devices configuration and system data as shown in Fig. 3-5.

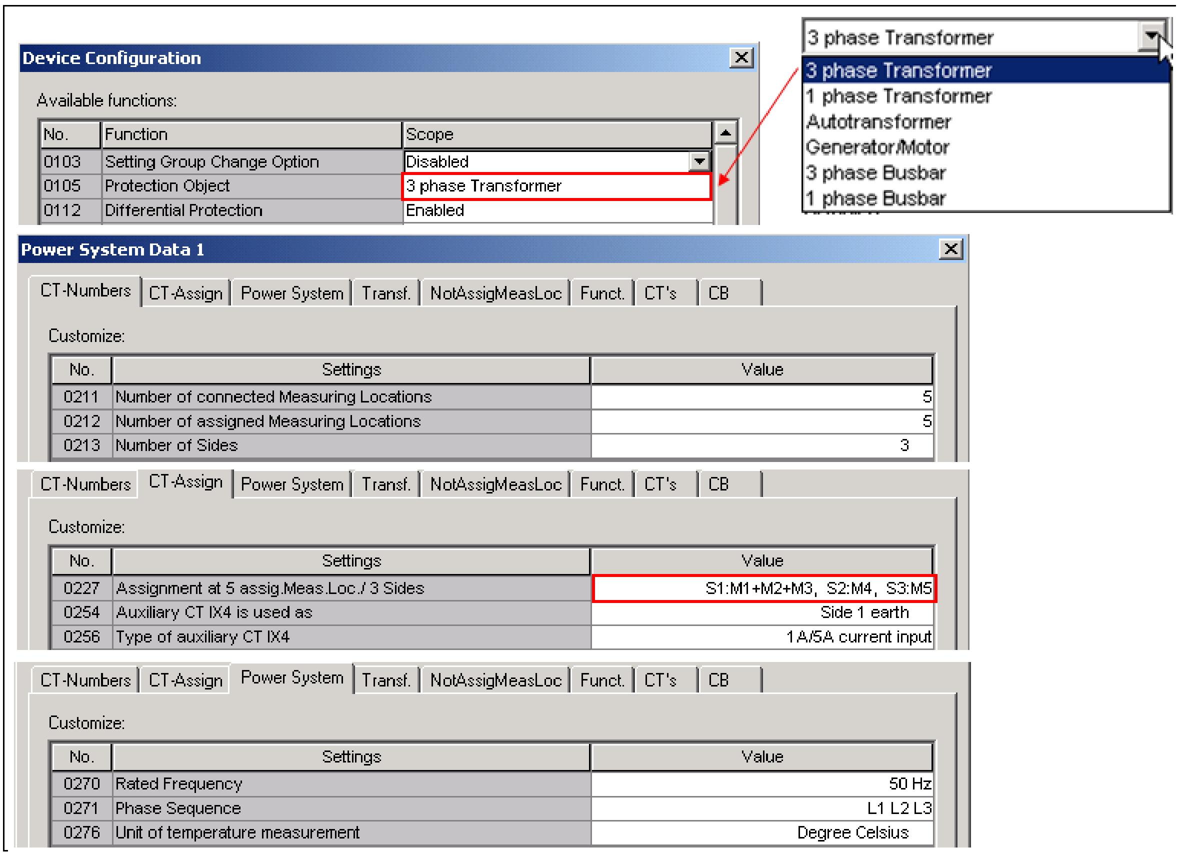
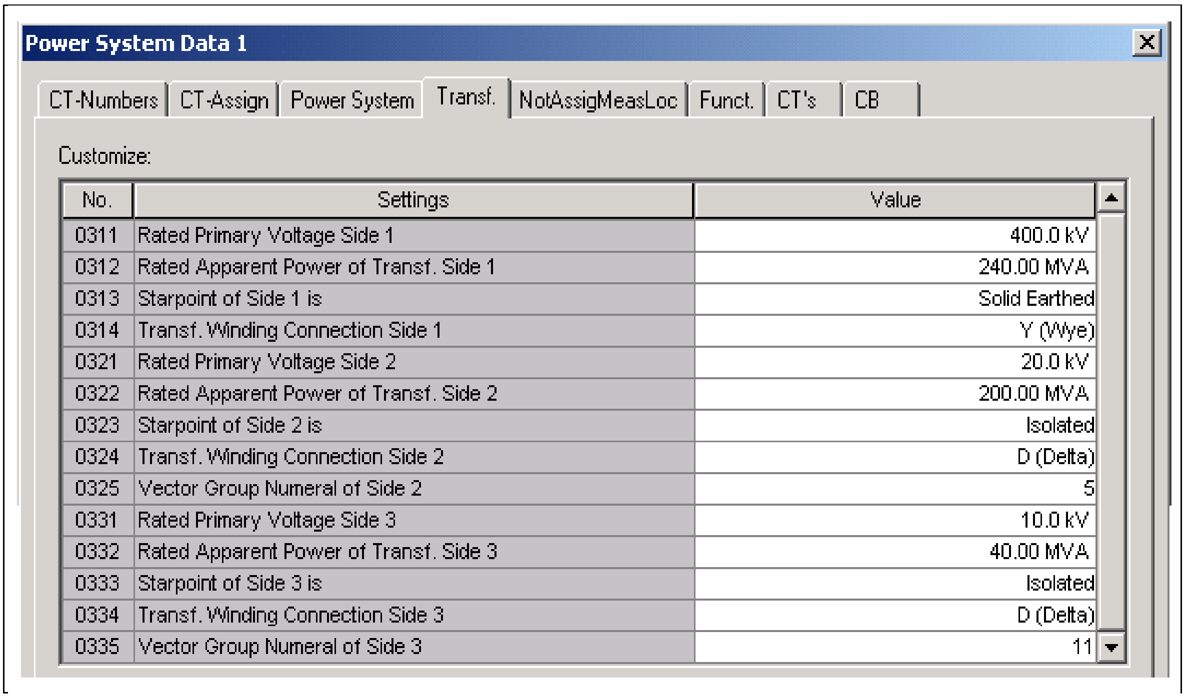


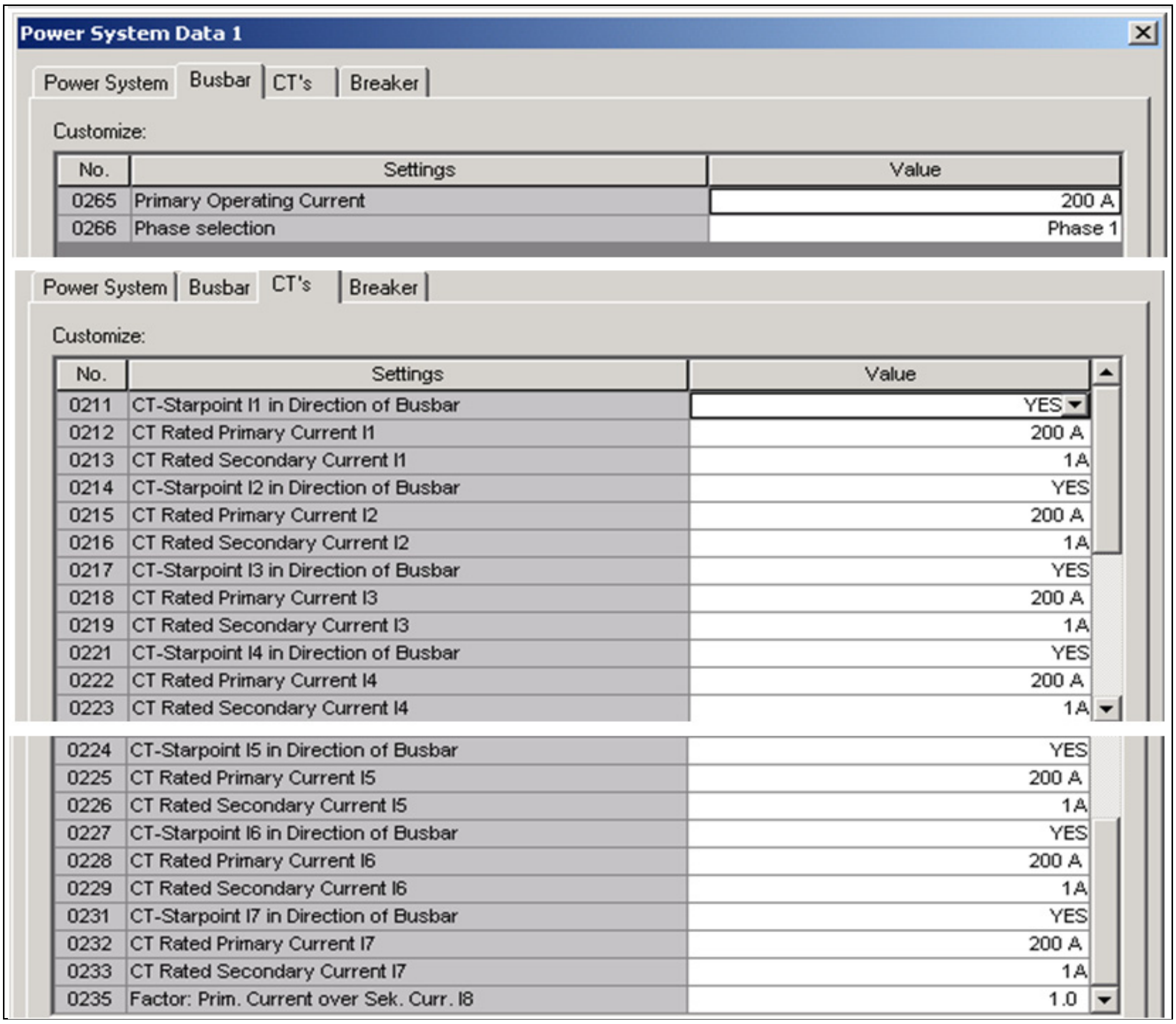
Fig. 3-5 Defining Power System Data

Select power transformer as an object that required to protecting. Select CT numbers and turns ratio. Define power transformer data including connection and vector group.



No.	Settings	Value
0311	Rated Primary Voltage Side 1	400.0 kV
0312	Rated Apparent Power of Transf. Side 1	240.00 MVA
0313	Starpoint of Side 1 is	Solid Earthed
0314	Transf. Winding Connection Side 1	Y (Wye)
0321	Rated Primary Voltage Side 2	20.0 kV
0322	Rated Apparent Power of Transf. Side 2	200.00 MVA
0323	Starpoint of Side 2 is	Isolated
0324	Transf. Winding Connection Side 2	D (Delta)
0325	Vector Group Numeral of Side 2	5
0331	Rated Primary Voltage Side 3	10.0 kV
0332	Rated Apparent Power of Transf. Side 3	40.00 MVA
0333	Starpoint of Side 3 is	Isolated
0334	Transf. Winding Connection Side 3	D (Delta)
0335	Vector Group Numeral of Side 3	11

Fig. 3-6 Defining Power Transformer to the Setting File

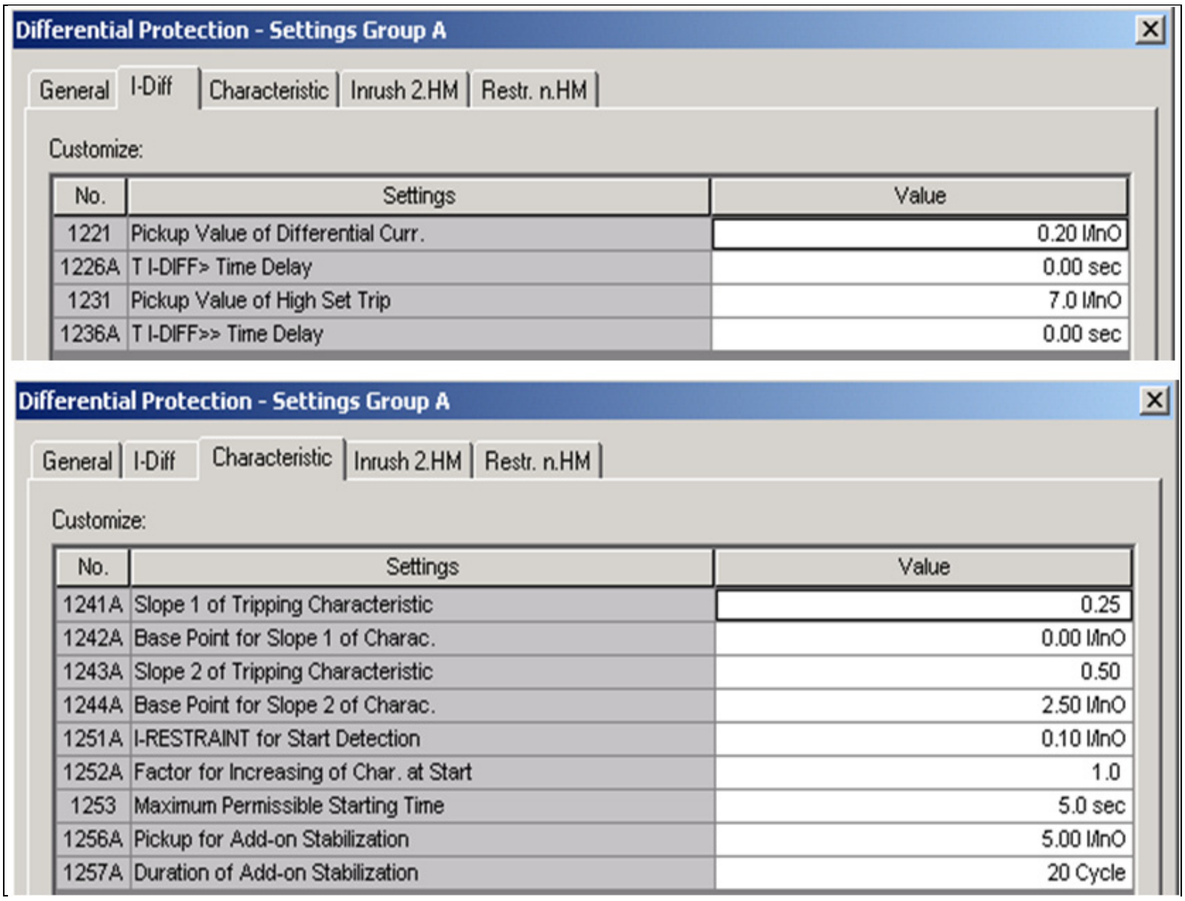


No.	Settings	Value
0265	Primary Operating Current	200 A
0266	Phase selection	Phase 1

No.	Settings	Value
0211	CT-Starpoint I1 in Direction of Busbar	YES
0212	CT Rated Primary Current I1	200 A
0213	CT Rated Secondary Current I1	1A
0214	CT-Starpoint I2 in Direction of Busbar	YES
0215	CT Rated Primary Current I2	200 A
0216	CT Rated Secondary Current I2	1A
0217	CT-Starpoint I3 in Direction of Busbar	YES
0218	CT Rated Primary Current I3	200 A
0219	CT Rated Secondary Current I3	1A
0221	CT-Starpoint I4 in Direction of Busbar	YES
0222	CT Rated Primary Current I4	200 A
0223	CT Rated Secondary Current I4	1A
0224	CT-Starpoint I5 in Direction of Busbar	YES
0225	CT Rated Primary Current I5	200 A
0226	CT Rated Secondary Current I5	1A
0227	CT-Starpoint I6 in Direction of Busbar	YES
0228	CT Rated Primary Current I6	200 A
0229	CT Rated Secondary Current I6	1A
0231	CT-Starpoint I7 in Direction of Busbar	YES
0232	CT Rated Primary Current I7	200 A
0233	CT Rated Secondary Current I7	1A
0235	Factor: Prim. Current over Sek. Curr. I8	1.0

Fig. 3-7 Defining Current Transformers to the Setting File

Define the pickup value of the differentia current, time delay, and the slop value of tripping characteristics.



Differential Protection - Settings Group A

General | I-Diff | Characteristic | Inrush 2.HM | Restr. n.HM

Customize:

No.	Settings	Value
1221	Pickup Value of Differential Curr.	0.20 I/InO
1226A	T I-DIFF> Time Delay	0.00 sec
1231	Pickup Value of High Set Trip	7.0 I/InO
1236A	T I-DIFF>> Time Delay	0.00 sec

Differential Protection - Settings Group A

General | I-Diff | Characteristic | Inrush 2.HM | Restr. n.HM

Customize:

No.	Settings	Value
1241A	Slope 1 of Tripping Characteristic	0.25
1242A	Base Point for Slope 1 of Charac.	0.00 I/InO
1243A	Slope 2 of Tripping Characteristic	0.50
1244A	Base Point for Slope 2 of Charac.	2.50 I/InO
1251A	I-RESTRAINT for Start Detection	0.10 I/InO
1252A	Factor for Increasing of Char. at Start	1.0
1253	Maximum Permissible Starting Time	5.0 sec
1256A	Pickup for Add-on Stabilization	5.00 I/InO
1257A	Duration of Add-on Stabilization	20 Cycle

Fig. 3-8 Defining Differential Current and Slop

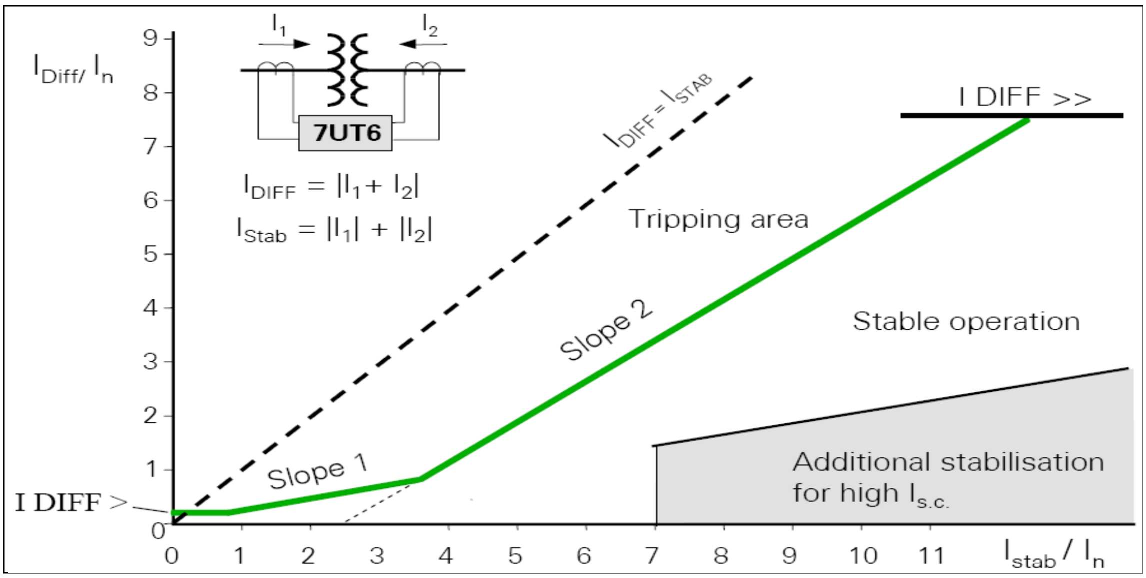


Fig. 3-9 Operating Characteristics of Differential Relay 7UT613

POWER SYSTEM PROTECTION & CONTROL STAGE 3B-PSP105

Textbook/Workbook

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